EDICON 2019

FOCUS
MICROWAVES GROUP

AURIGA
PULSED IV

mesuro

Active Modulated Load Pull

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Business Development Manager

About Us

FOCUS MICROWAVES

Focus Microwaves is a pioneering engineering company, built around the innovations of its founder Dr. Christos Tsironis, who developed **his first manual tuner in 1973**, and is the inventor of most existing electro-mechanical tuner families; and the engineering and manufacturing skill of its highly motivated and experienced team of Technicians and Engineers, who have been trained and encouraged to develop new technologies and listen to and support our customers. Starting in 1988, Focus has meanwhile become the main supplier of advanced Load Pull and Noise tuner systems.

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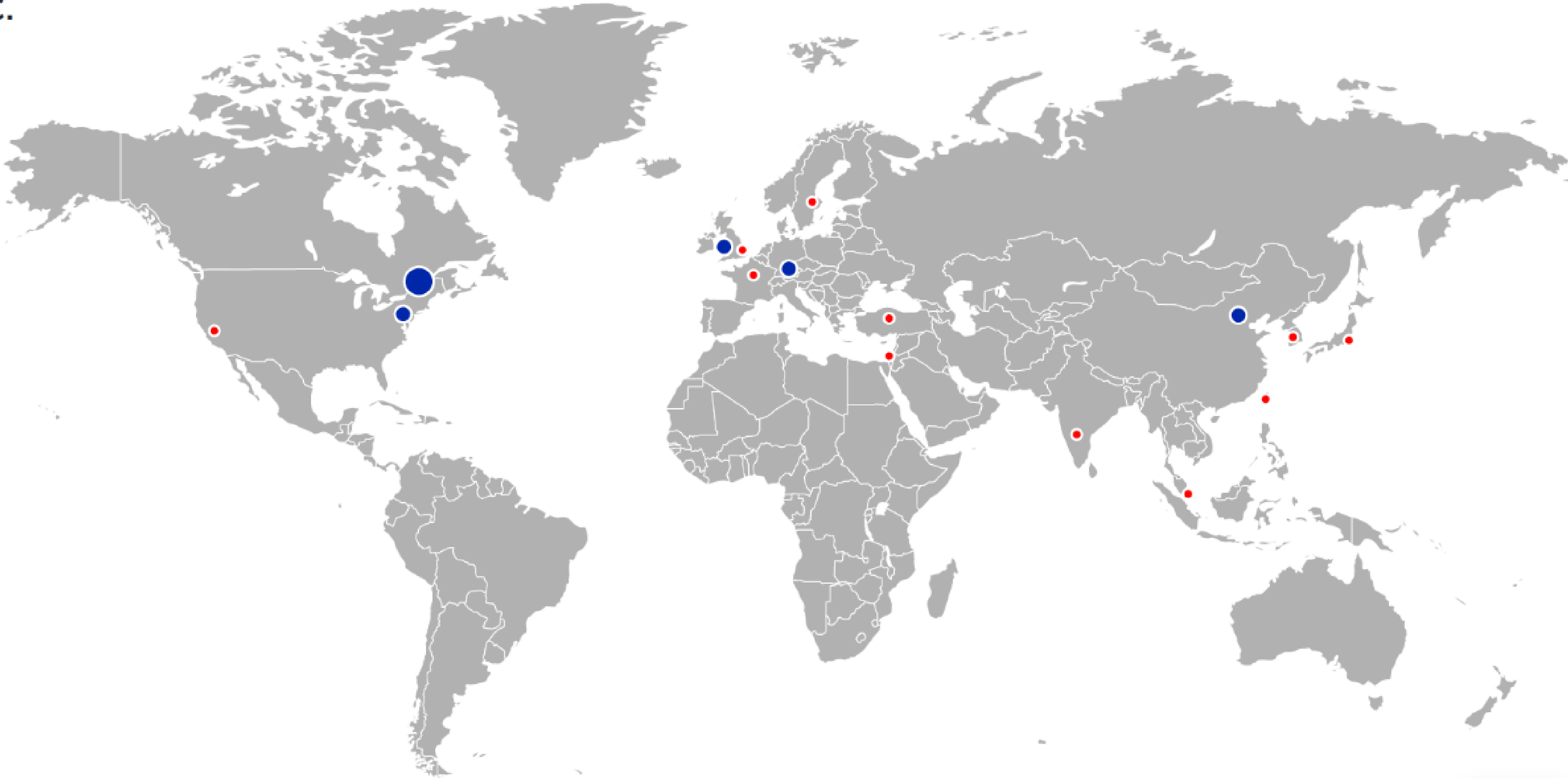


Outline

- **Load-pull Measurement Basics**
  - Scalar Load-pull
  - Vector Load-pull
  - Hybrid Load-pull
  - Active Load-pull
  - Wave based Load-pull to Behavioural Model
- **RAPID Measurement Setup**
  - Comparisons of RAPID and traditional LP
  - Effects of modulation BW
- **RAPID Load-pull System Description**
  - System Architecture
  - Vector Calibration
  - Active Loop Calibration
- **RAPID CW Measurements and Comparison with Traditional LP Setups**
- **RAPID Modulated Load-pull Measurements**
- **Conclusions**

Load Pull Basics

Introduction to Load-Pull

What is Load-Pull

Load Pull

- An accurate measurement of key nonlinear performance parameters, including output power, gain, efficiency, linearity, etc. as a function of the fundamental load impedance, which is the key design parameter is typically referred to as *load-pull*.

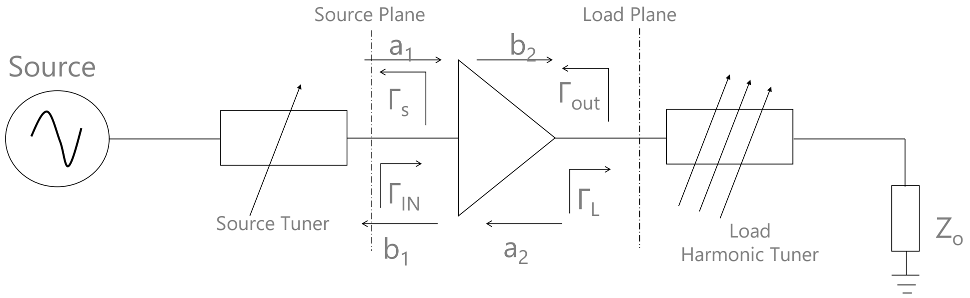
Load Pull procedure consists of:

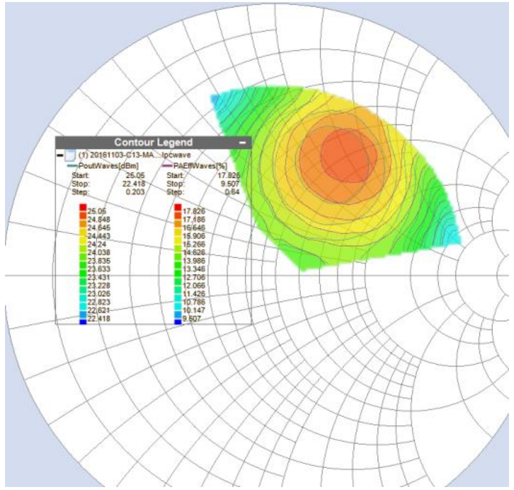
- Assessing the performance of the DUT qualitatively under different impedances
- Establishing a condition under which optimal performance can be obtained

Why Load and Source Pull ?

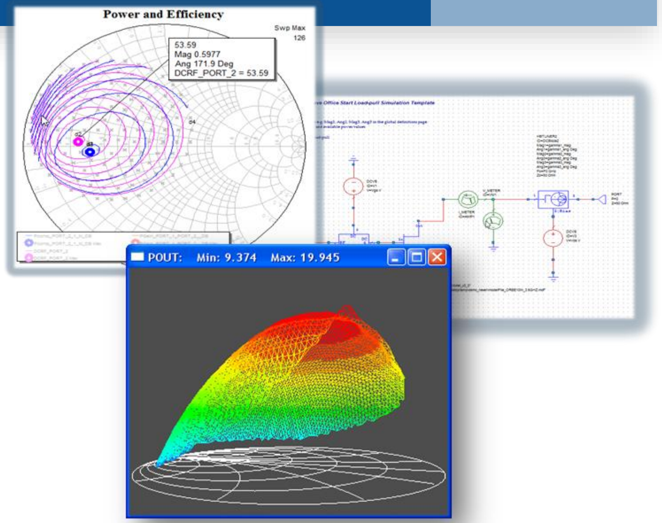
- Design, optimize RF/µW power amplifiers & transistors
- Design matching networks of transistors
- Develop a semiconductor process
- Synthesize impedances in Smith Chart

Load-Pull Contours



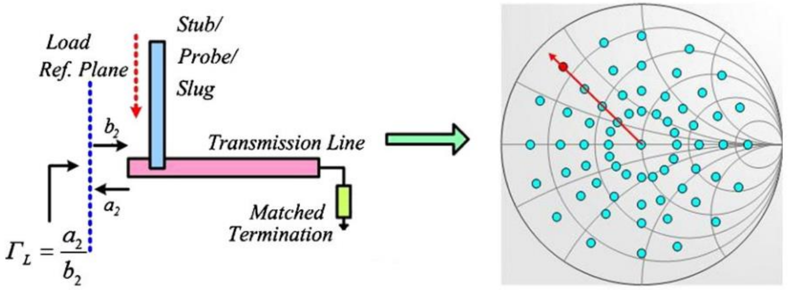


Load Pull Measurements

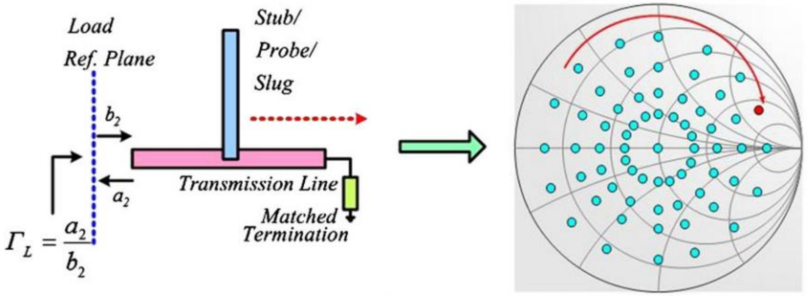


- Impedance control is provided by a passive tuner or an active tuner.

- An impedance tuner generates controllable reflection factor (Impedance) over a certain frequency range.



The movement of a stub/probe/slug in the vertical direction changes the magnitude of the reflection factor



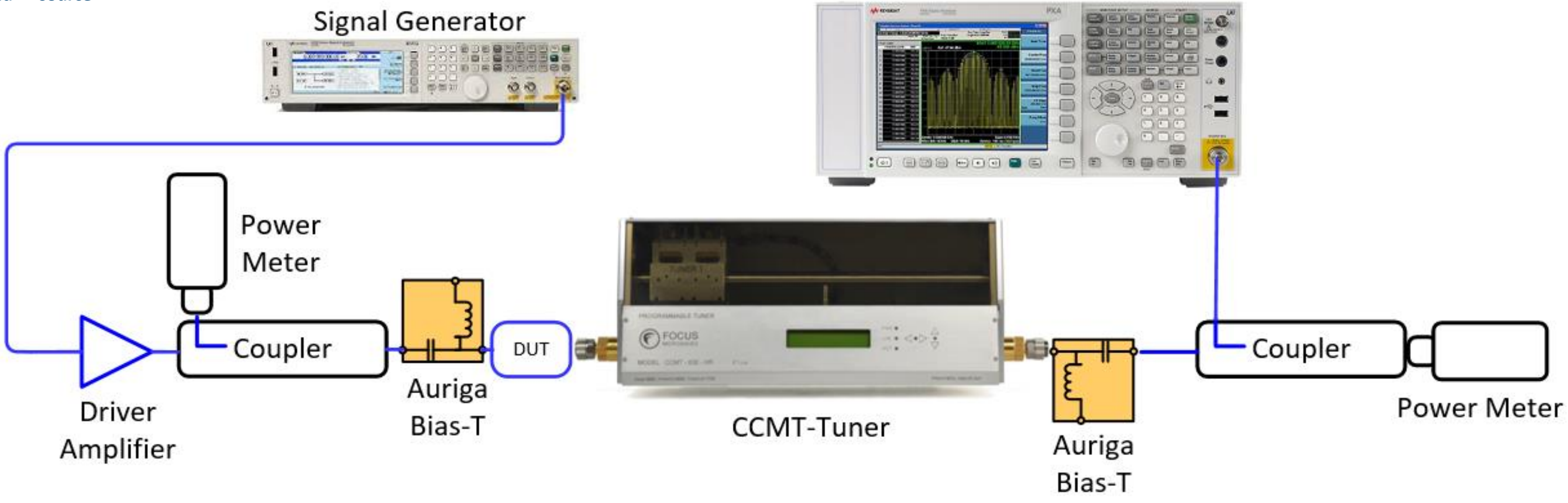
The movement of a stub/probe/slug in the horizontal direction alters the phase of the reflection factor

Load Pull setups -Scalar Load Pull

The typical scalar load pull setup comprises a signal generator, a power divider, two RF power sensors, a power meter, some DC bias networks and two fundamental tuners.

Measurements include:

- **Pin, Pout, Gain$_{trd}$, ACPR,**
- **Γ_{Load}, Γ_{source}**



Load Pull setups – Vector Load Pull

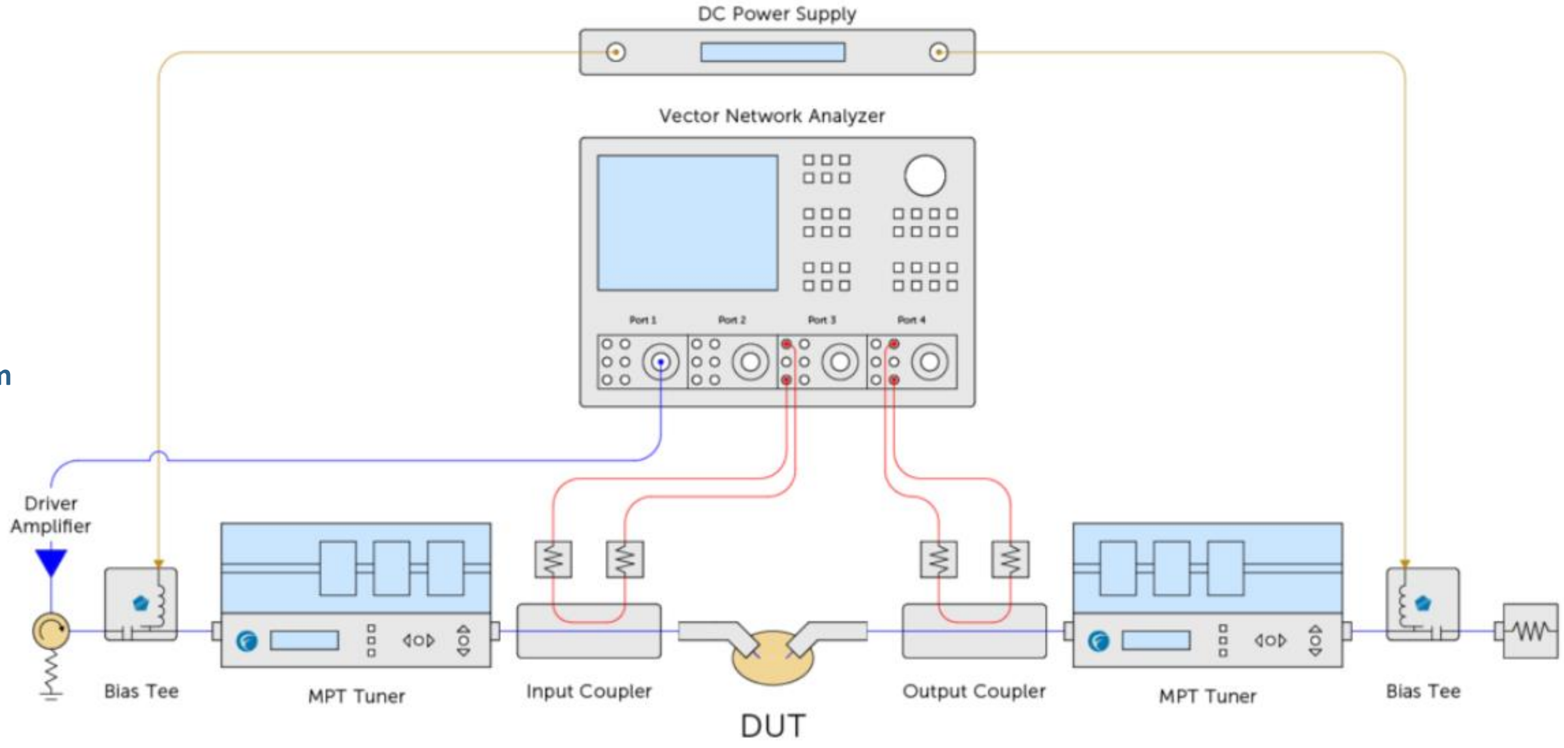
Vector Load Pull allows measuring the input and output large signal impedances of the DUT, the input delivered power, the Power added efficiency, and the real time incident and reflected waves thus not relying on mechanical tuner repeatability

Measurements include:

- **Pin, Pout, $Gain_{trd}$,$Gain_{pwr}$**
- **PAE, ACPR**
- **Γ_{Load}, Γ_{IN}**

Major advantage:

- **Speed**
- **Higher dynamic range**
- **Time domain Waveform**

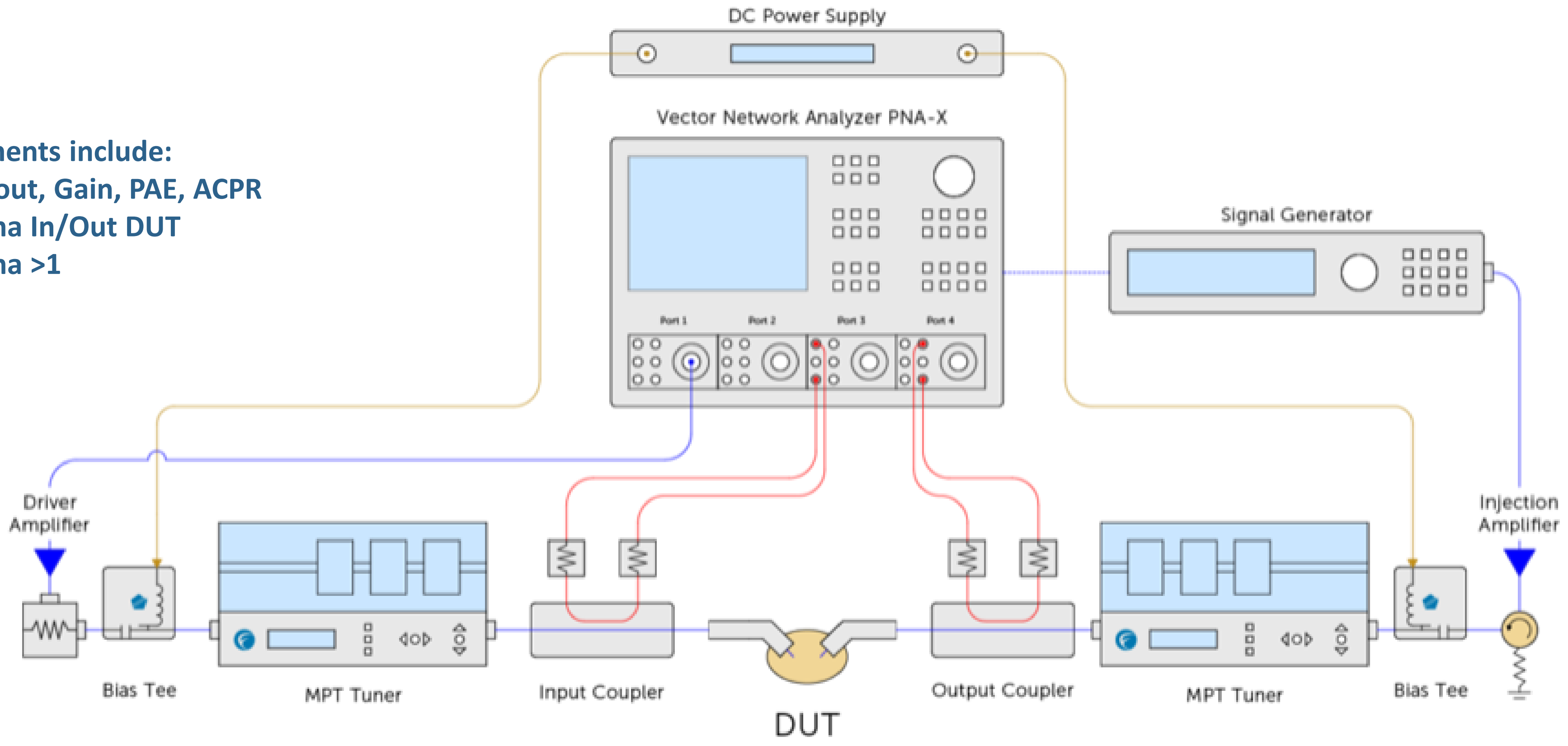


Load Pull setups – Hybrid Load Pull

As per its name a hybrid load pull system includes both an active loop as well as the passive tuners. The hybrid system has all the advantages of speed and tuning range of an active system as well as the power handling of a passive system.

Measurements include:

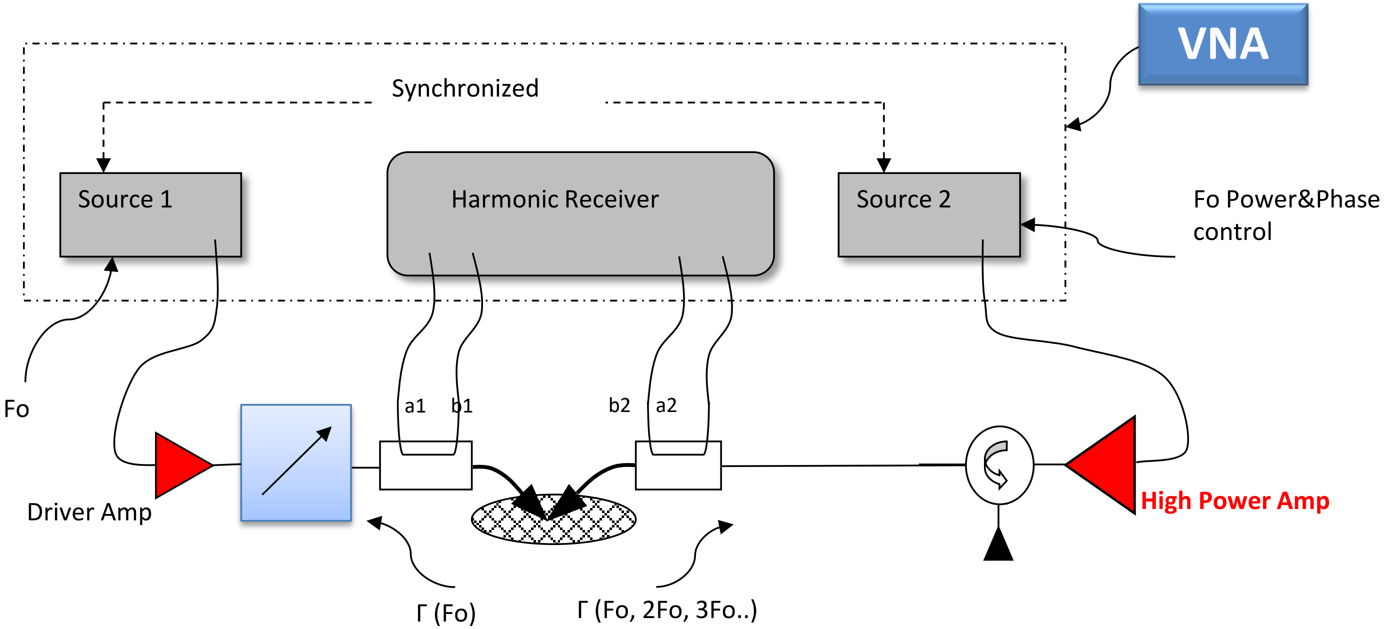
- **Pin, Pout, Gain, PAE, ACPR**
- **Gamma In/Out DUT**
- **Gamma >1**



The tuning algorithm finds the <u>optimum compromise</u> for tuner loss and P_{inj} for reaching Γload.

Active Load Pull – Basic Principal

To achieve maximum reflection including the ability to control impedance anywhere, inside and outside of the Smith chart; reduced system footprint and perhaps most importantly speed, a full active LP system is used. Using the vector receiver architecture, Fundamental and/or harmonic load pull can be undertaken using a variety of configurations, either employing internal VNA sources or external RF sources and a PLL interface. By employing a broadband coupler network and in the case of harmonic measurements a reconfigurable multiplexer harmonic data can also be captured for use by designers.



The disadvantages of this setup is that a very high power active loop amplifier is required to synthesize low impedance points.

Introduction to RAPID

Load Pull Setups - RAPID

Key Benefits

Dramatically improve Test-Bench Throughput

- Ultra-fast impedance control and measurement (up to 50 Measurements/Second including DC)

Improved Modulated Measurement Capability

- 100MHz real time bandwidth with wideband impedance control and/or circuit emulation
- Ability to de-skew non-ideal tuner impedance over bandwidth

Reduced Test-Bench CAPEX

- Self Calibrating – No VNA required
- Real-Time power measurements
- Real-Time Spectral/Vector measurements
- No Spectrum Analyzer

RAPID Load Pull

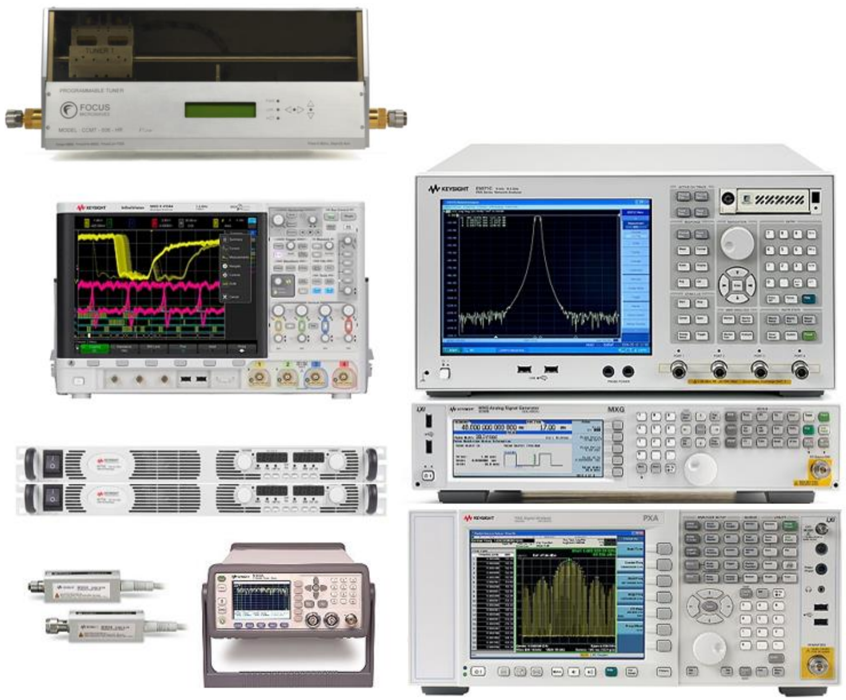
RAPID vs Traditional LP

Key Specifications	Active	Passive
Frequency Range	0.1-40GHz	10MHz - 110GHz
Dynamic Range	Dependent on Vector Receiver used Ex: PNA-X / ZVA	
Wideband Impedance Control	A few hundred MHz	N/A cannot control a wideband impedance
Tuning Range	Gamma >1	Limited by loss of cable from tuner to DUT
Power Handling	High, but the loop amplifier size is directly proportional to the DUT's impedance and Output Power	Passive tuners can handle very high power and have very high Dynamic range. Tuner perfomance and setup are not affected by the DUT's output power. The only power limitation is restricted by the connector type of the tuner
Integratiblity	Very Good as the user does not need to worry about loss between the tuner and the DUT, the loop amplifier will conpensate for the loss.	Challenging when going low 1-2GHz. As the frequency of operations becomes lower the size of the tuner proportionally longer making it more challenging to mount on a probe station.

Active – Passive Load Pull

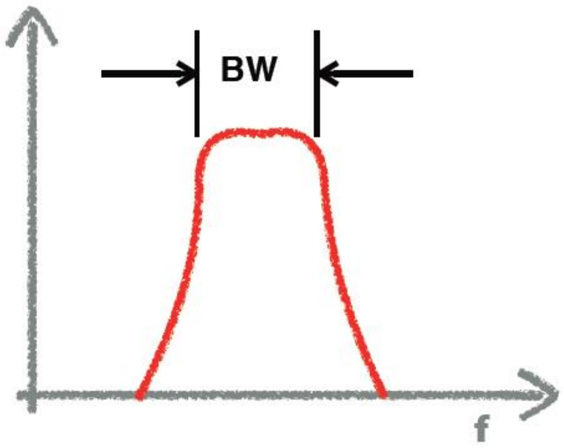
RAPID Load Pull

Passive Load Pull

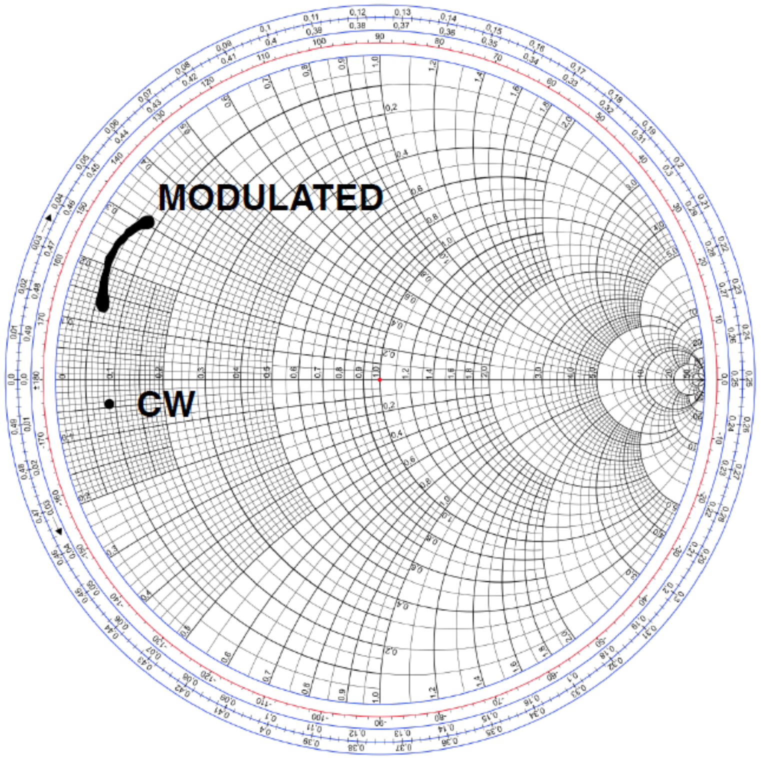


Modulation Load Pull

Modulation bandwidth comparison



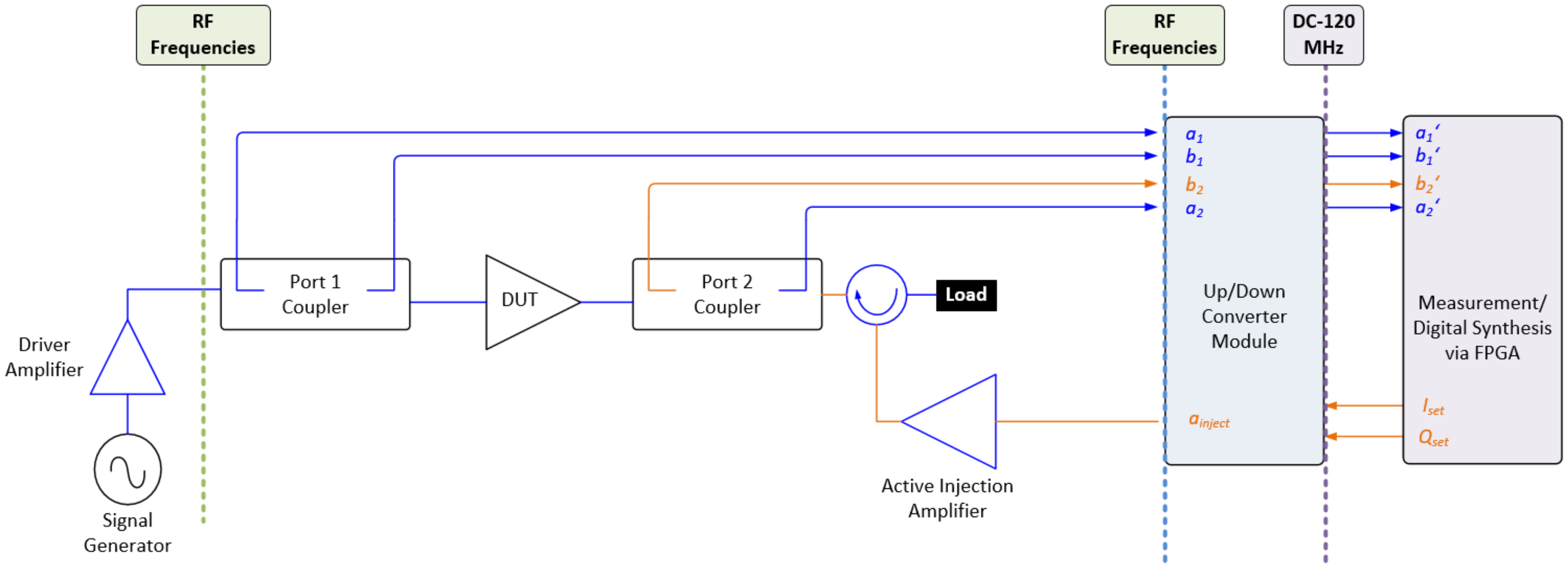
Impedance Skew



RAPID LP System Description

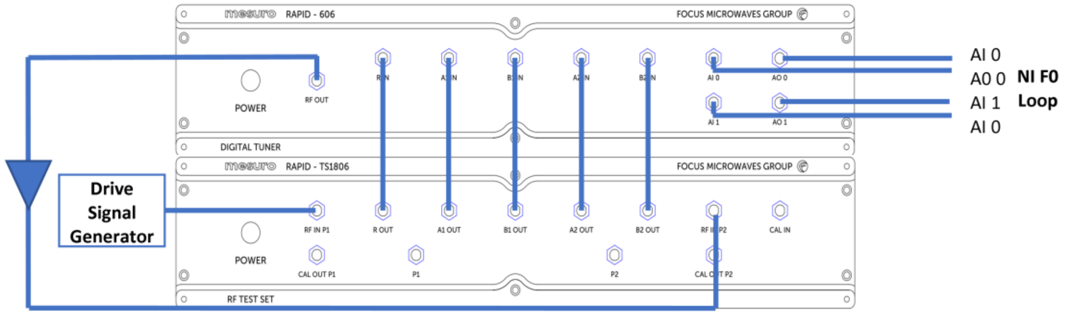
Active Load Pull

- The Rapid Load-pull system is a programmable digital, PXI-based, feedback active load-pull tuner that maximizes throughput of a load-pull bench.
- The input and output port of the DUT are fed via a dual-directional couplers to a down converter module.
- The baseband data is then processed in an FPGA module and sent to the up converter to form the injected signal.

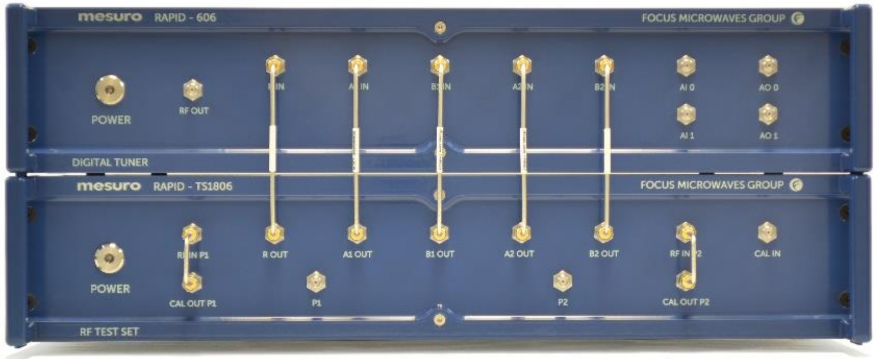


RAPID Modular Architecture

1 Frequency Fundamental Diagram

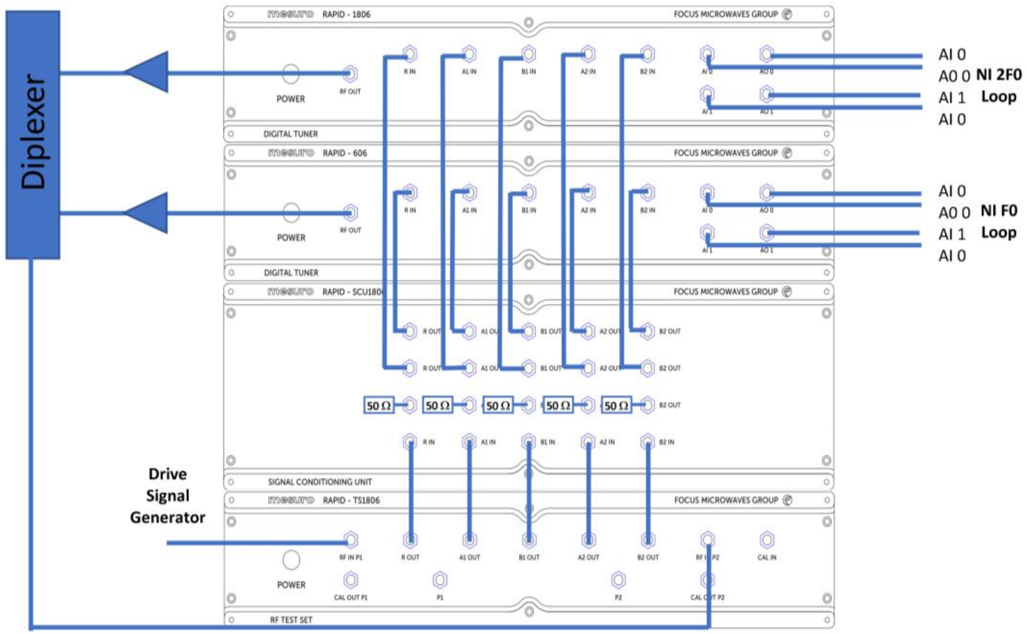


1 Frequency Fundamental Setup



RAPID Modular Architecture

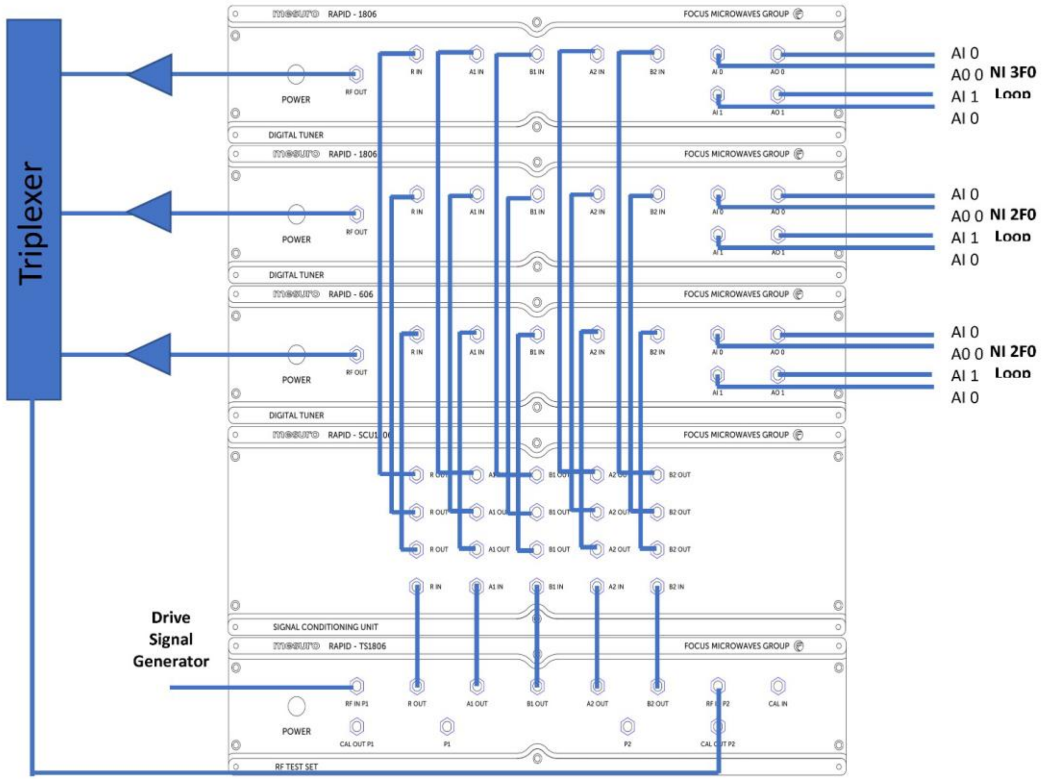
2 Frequency Diagram



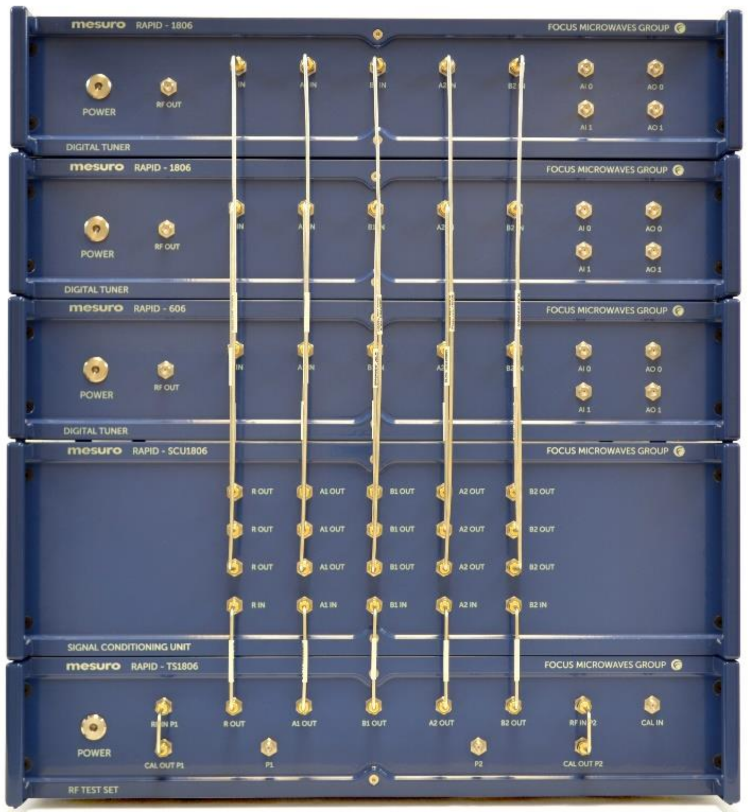
2 Frequency Setup

RAPID Modular Architecture

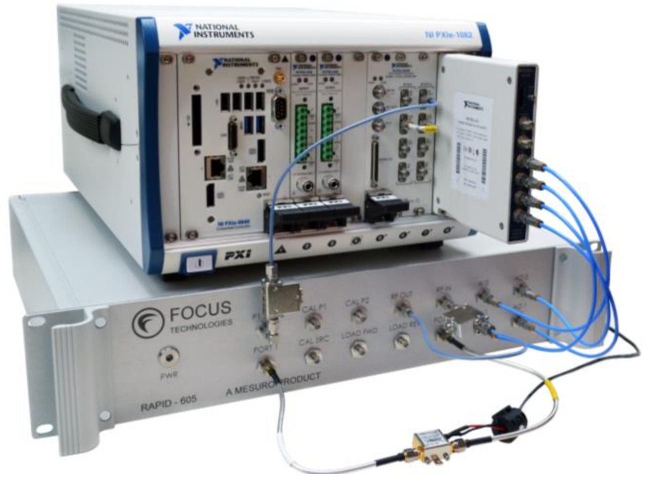
3 Frequency Diagram



3 Frequency Setup



RAPID Hardware Architecture



- The RAPID series of tuners leverages the performance and reliability of National Instrument RF/uW hardware. For basic CW testing, the RAPID series of tuners requires at minimum a PXI chassis (with 10MHz timing), a real-time FPGA and Extension card.

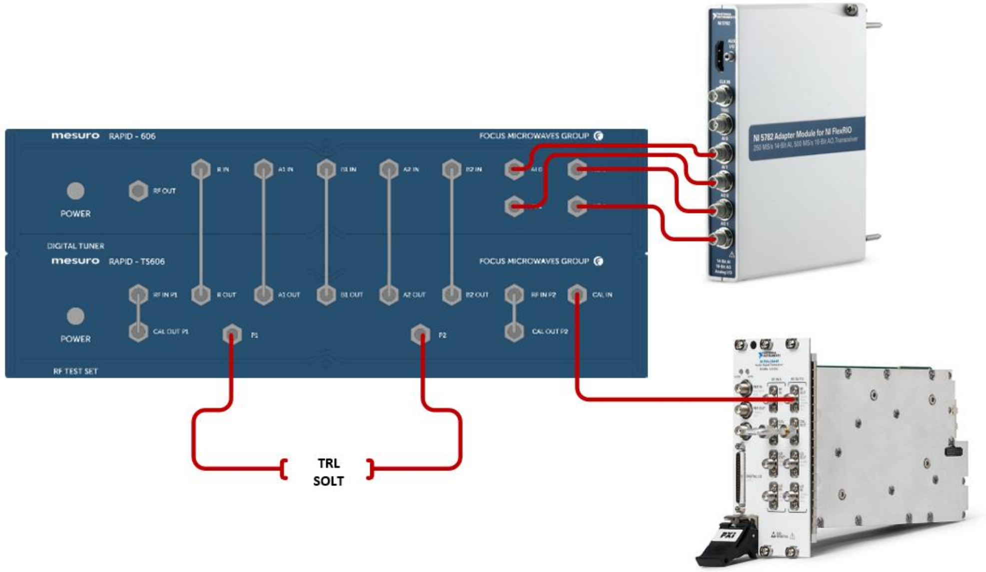
- Functionalities like RF pulsed, advanced carrier modulation and DC measurements can be added to the system by simply adding the desired PXI module to the PXI Chassis. This makes the system modular and easily upgradable

S-Parameter & Power Calibration

- The system can measure the forward and reverse travelling waves, so unlike a passive tuner calibration, there is **no requirement for an external VNA.**

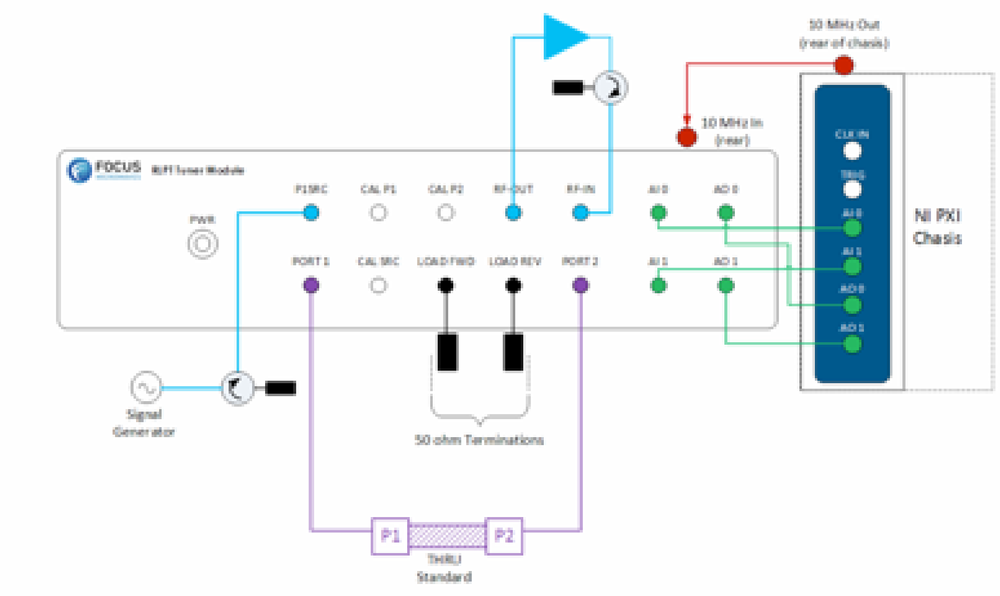
- The first step is therefore to perform a one or two port VNA calibration, this is performed as a **standard SOL, SOLT, or TRL** cal at the desired reference plane.

- A power meter can then be used to calibrate for accurate power measurements, by attaching a power meter to the reference plane.



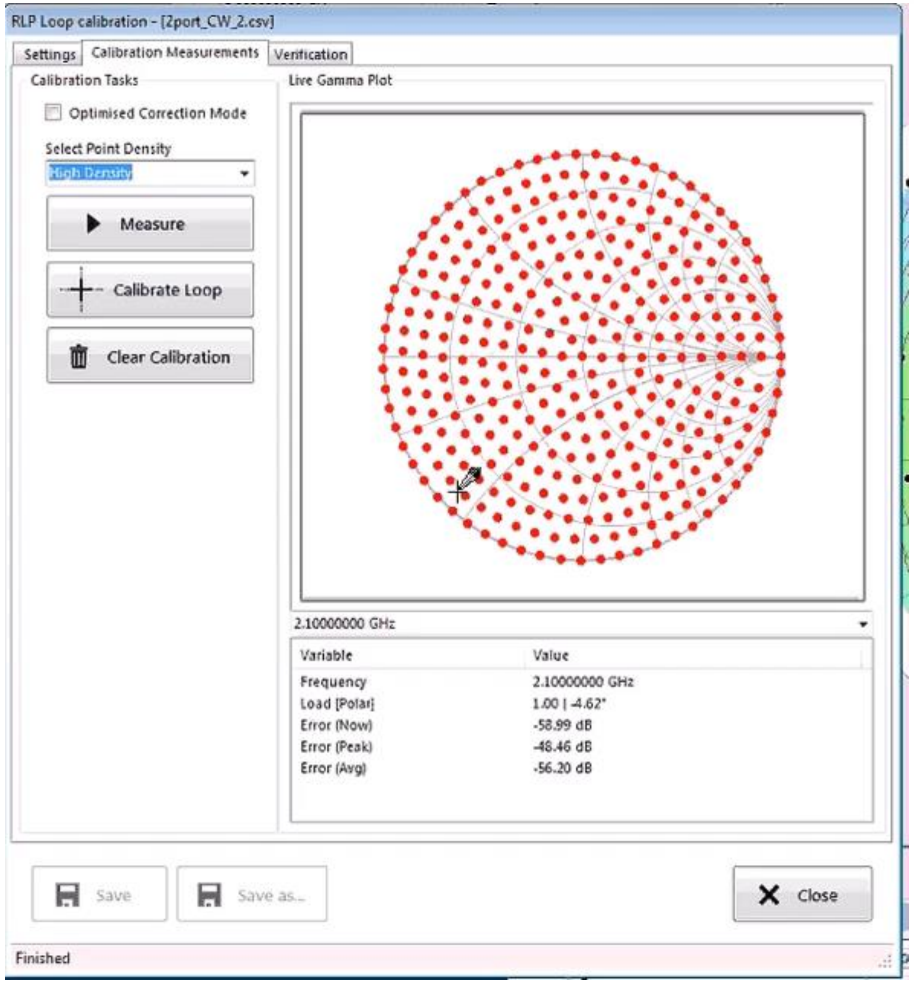
Rapid Active Loop Calibration

- The loop calibration must be performed before attaching the device.
- It is used to calculate the error coefficients associated with the feedback loop.
- Once these error coefficients have been found the user can accurately set any impedance on the smith chart without the need for interpolation.

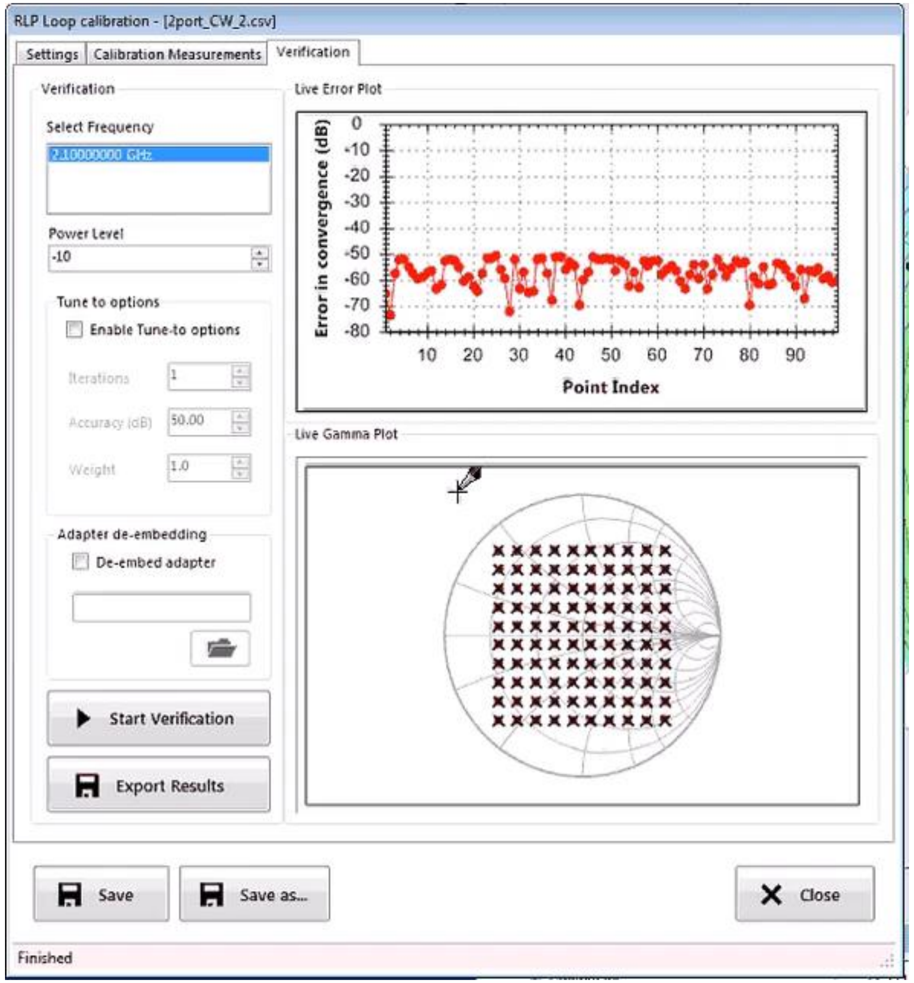


CW Signal Measurements

CW – Active Loop Calibration



CW – Impedance Synthesis Verification



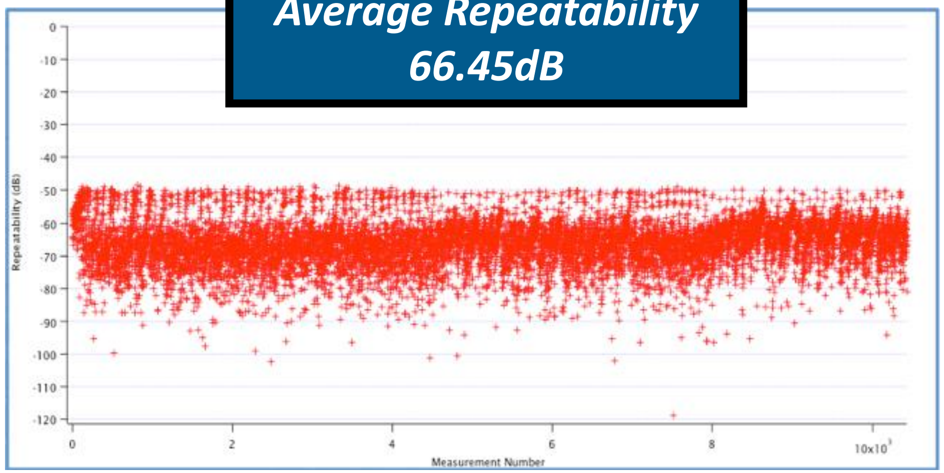
Long Term Stability

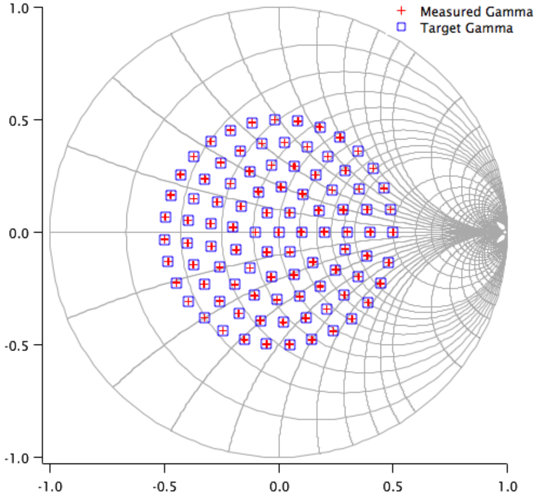
DEVICE TESTING

Long Term Stability

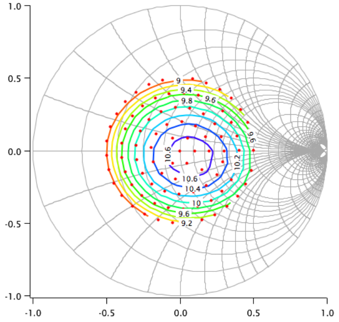
- Test conducted with a DUT present
- Power and impedance were swept for a 65 hour period.
- Desired tolerance is set to 50dB.

Average Repeatability 66.45dB

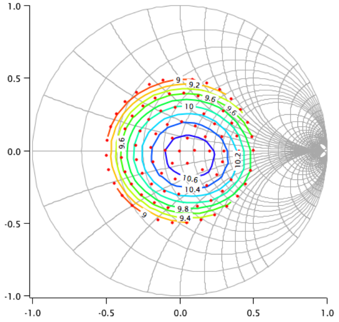




Load Pull Pattern



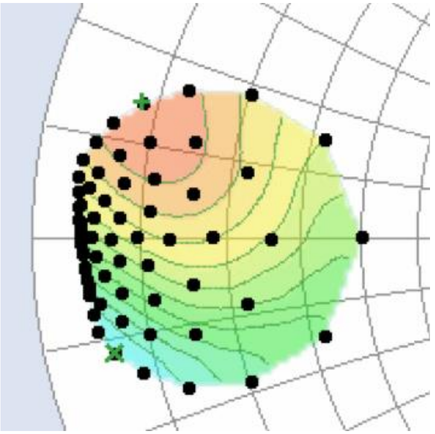
Start of Test



After 65 Hrs

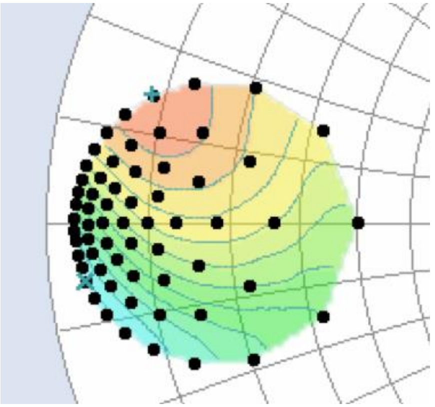
CW Measurement Comparison

Power Contours & Swept Power



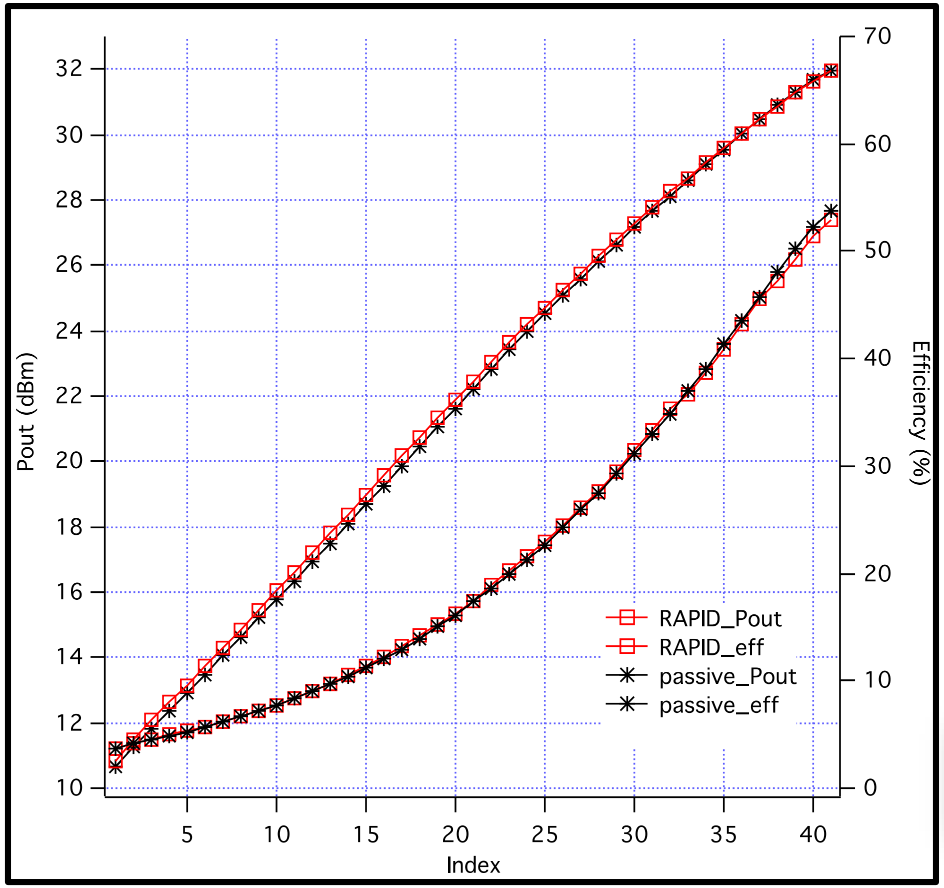
Passive Load-Pull

* note that passive tuner cannot quite reach the edge of the desired 5 ohm circle, but active can overcome this issue.



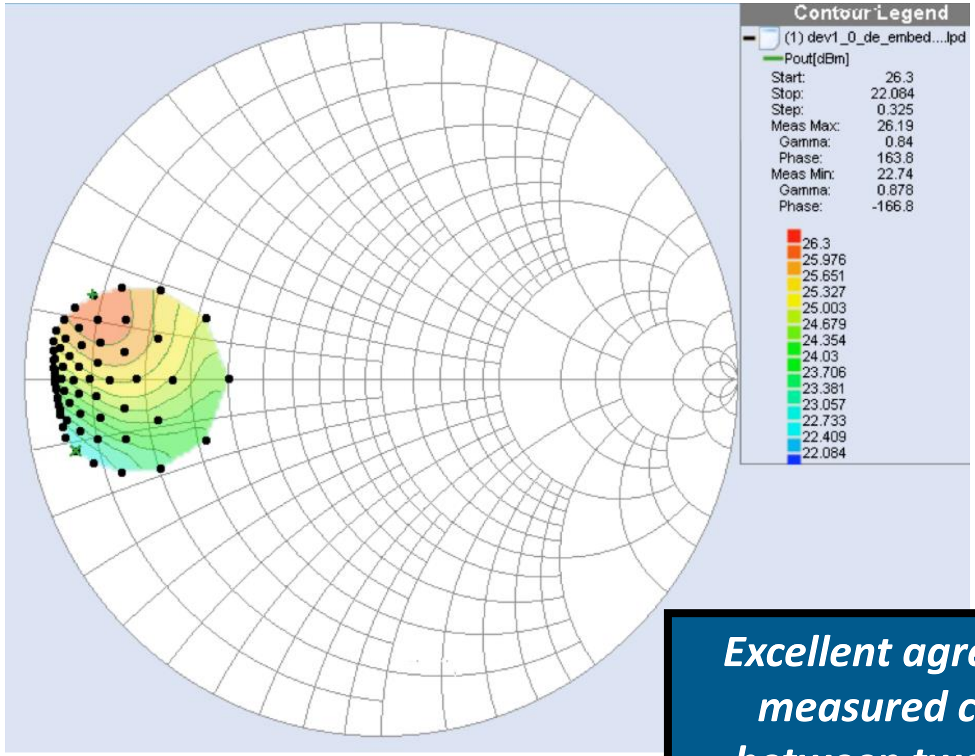
RAPID Load-Pull

Power Sweep Measurements

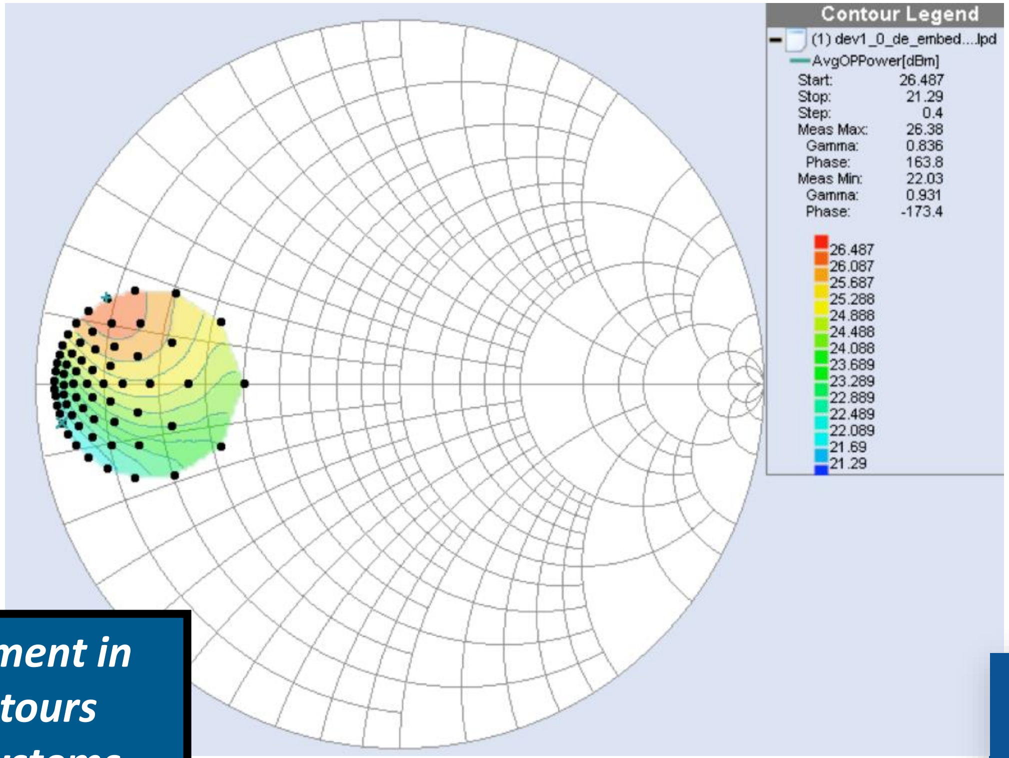


Measurement Comparison

Passive Load Pull



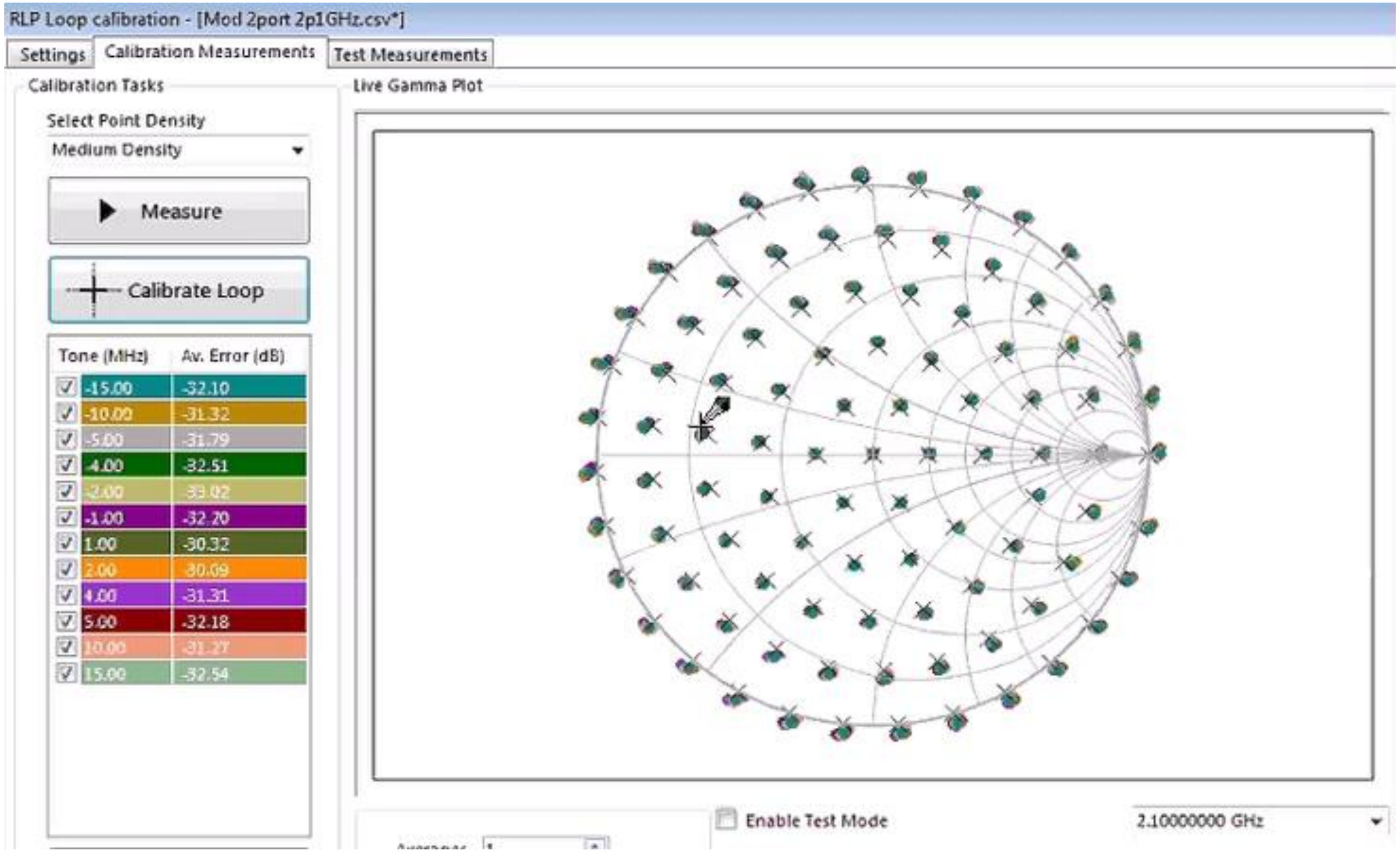
RAPID Active Load Pull



Excellent agreement in measured contours between two systems

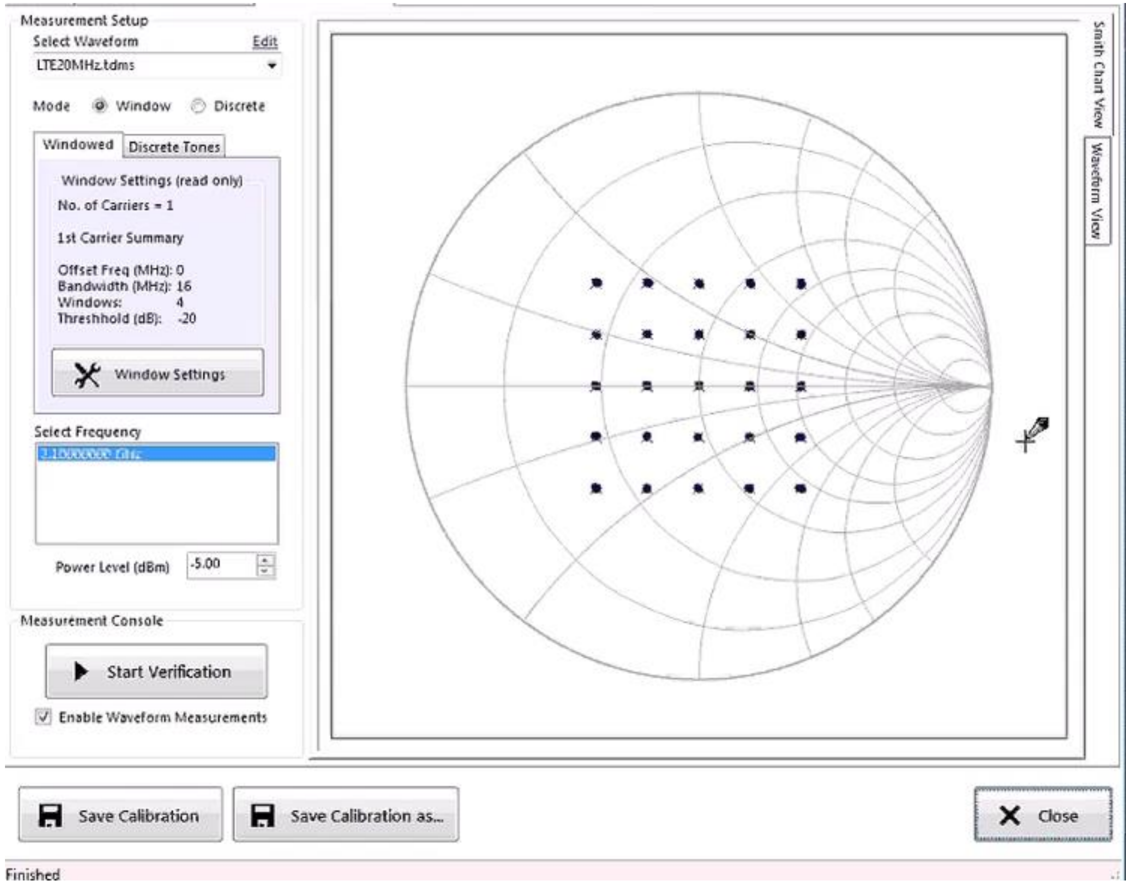
Modulated Signal Measurements

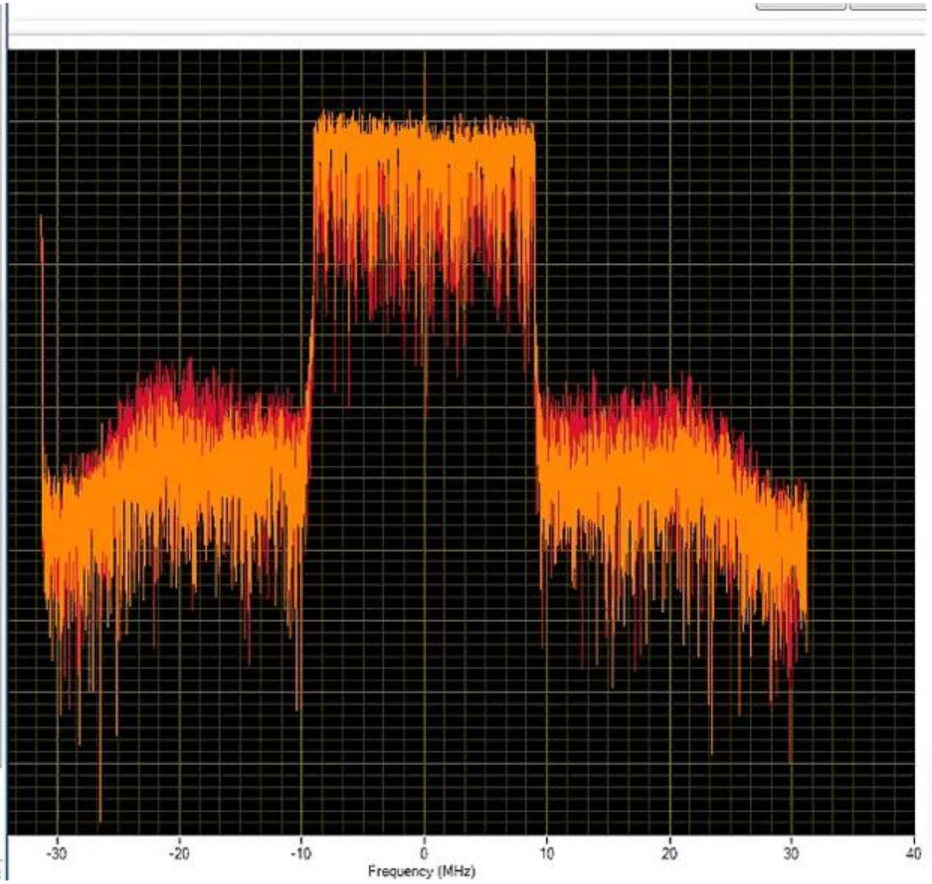
Modulated – Active Loop Calibration



Modulated – Verification

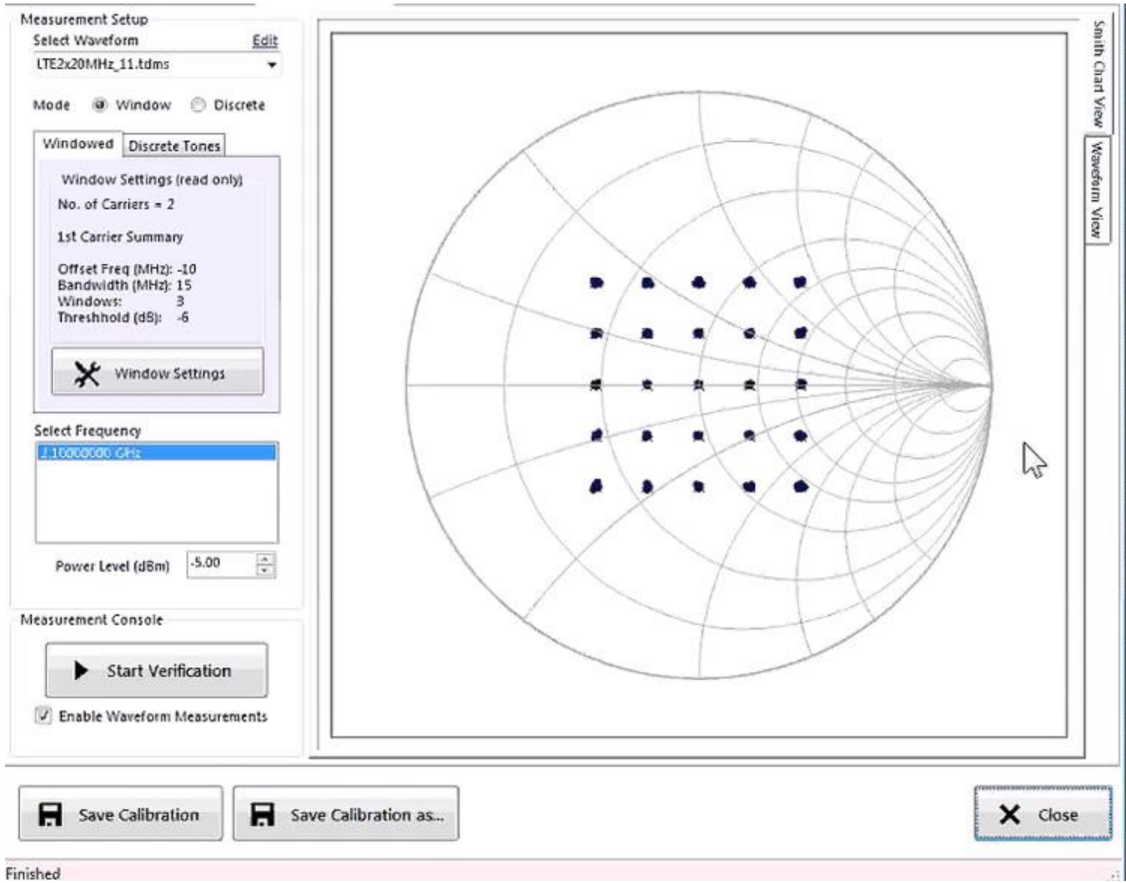
Example 20MHz LTE Pattern Verification

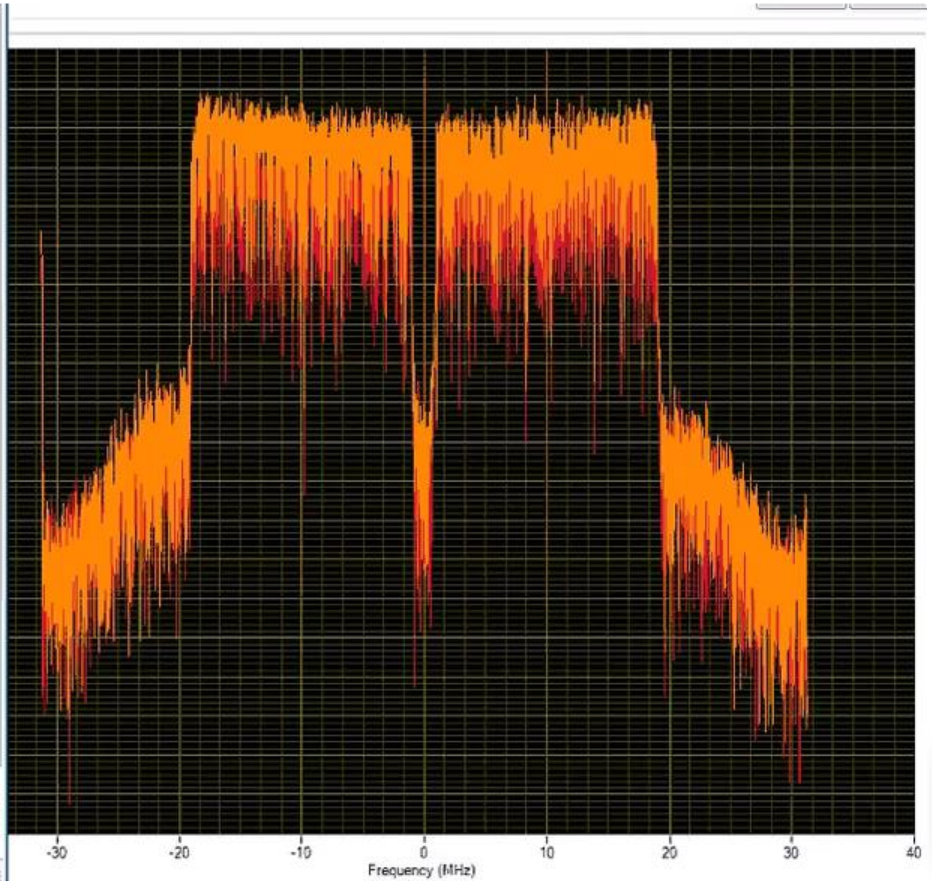




Modulated – Verification

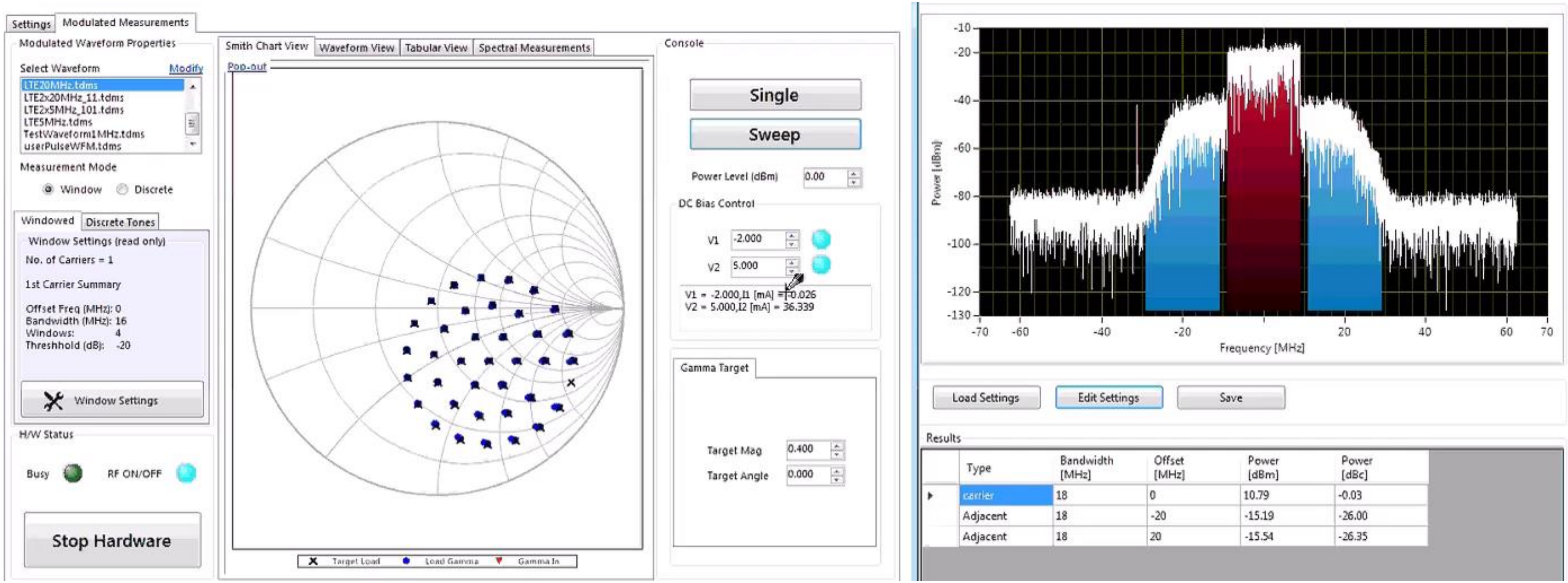
Example 2x20MHz LTE Pattern Verification





Modulated - Measurements

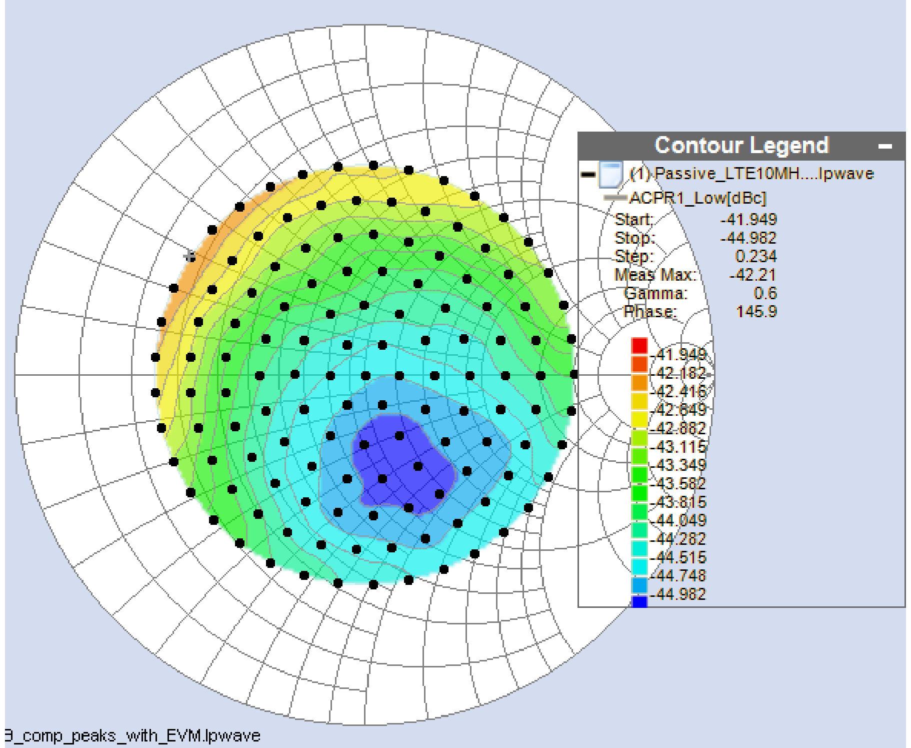
Example 20MHz LTE ACPR Measurements



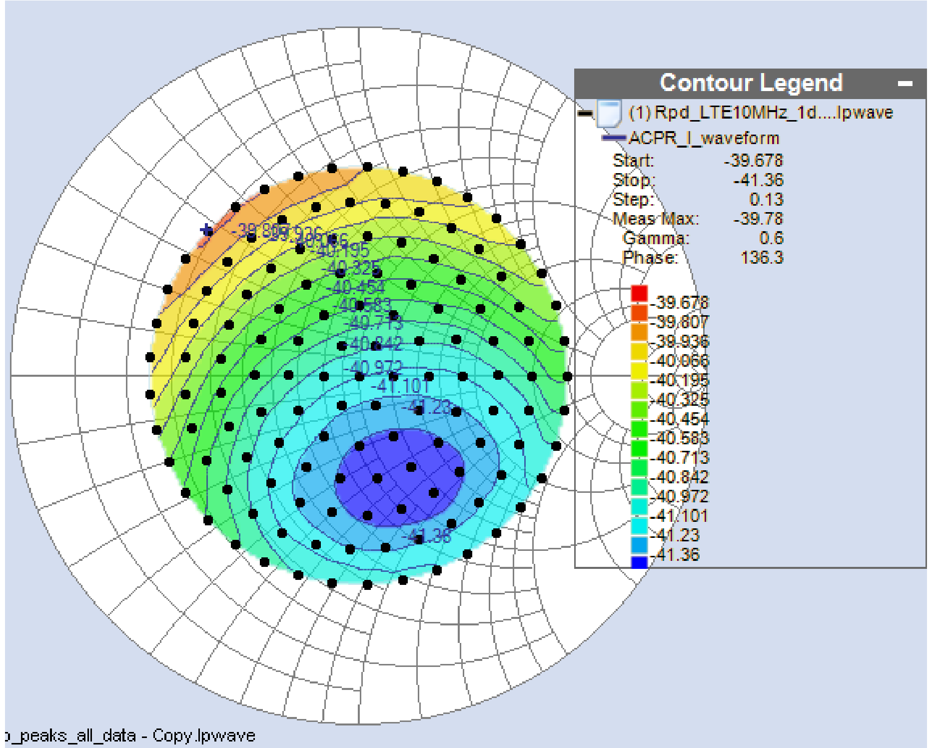
ACPR- Comparison RAPID and Passive LP setups

ACPR_low with 1 dB compressed peaks

Passive system



Rapid system

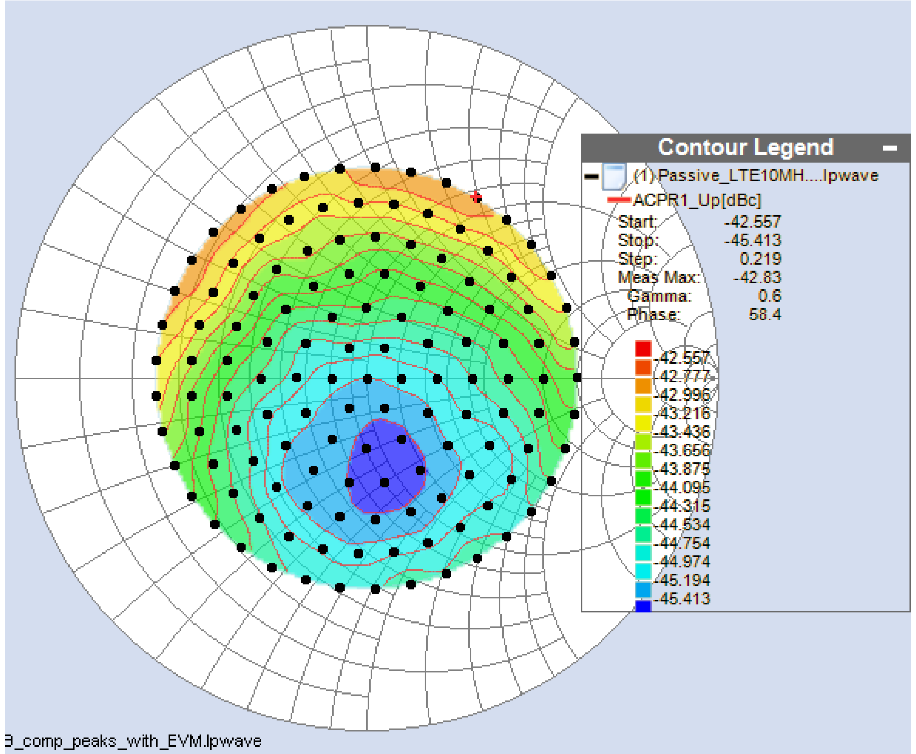


*Passive measurement result contours are somewhat “noisy”. This can be reduced by averaging or by reducing resolution bandwidth of the signal analyser which increases measurement time.

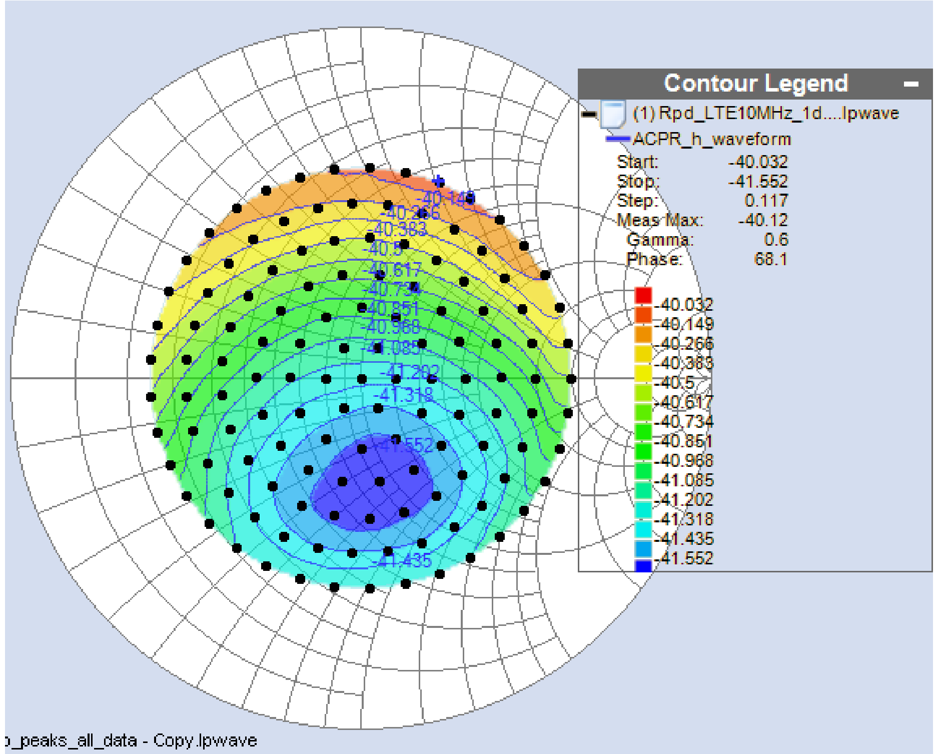
ACPR- Comparison RAPID and Passive LP setups

ACPR_low with 1 dB compressed peaks

Passive system



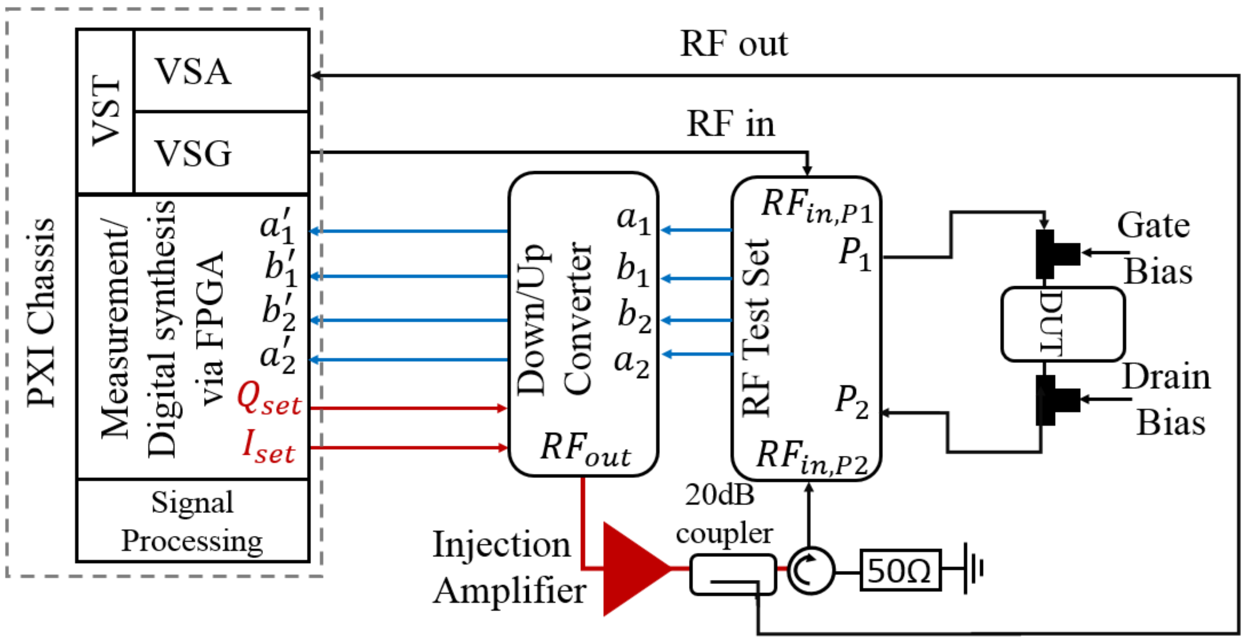
Rapid system



*Passive measurement result contours are somewhat “noisy”. This can be reduced by averaging or by reducing resolution bandwidth of the signal analyser which increases measurement time.

Digital Predistortion

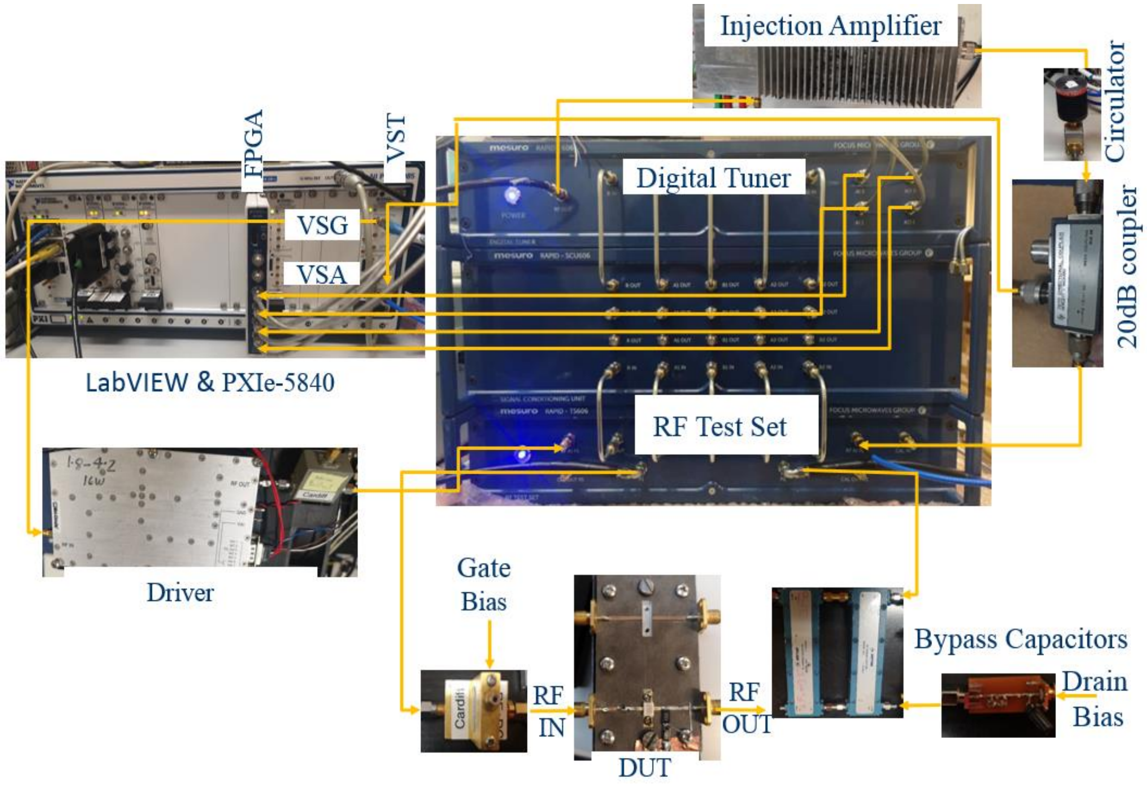
- The system hardware is implemented within an NI PXI vector signal transceiver (VST).
- This VST is able to support up to 1 GHz signal bandwidth up to a maximum operational frequency of 6 GHz.
- The proprietary DPD algorithm is implemented in a NI software package called RFIC.



Digital Predistortion under Non 50Ω

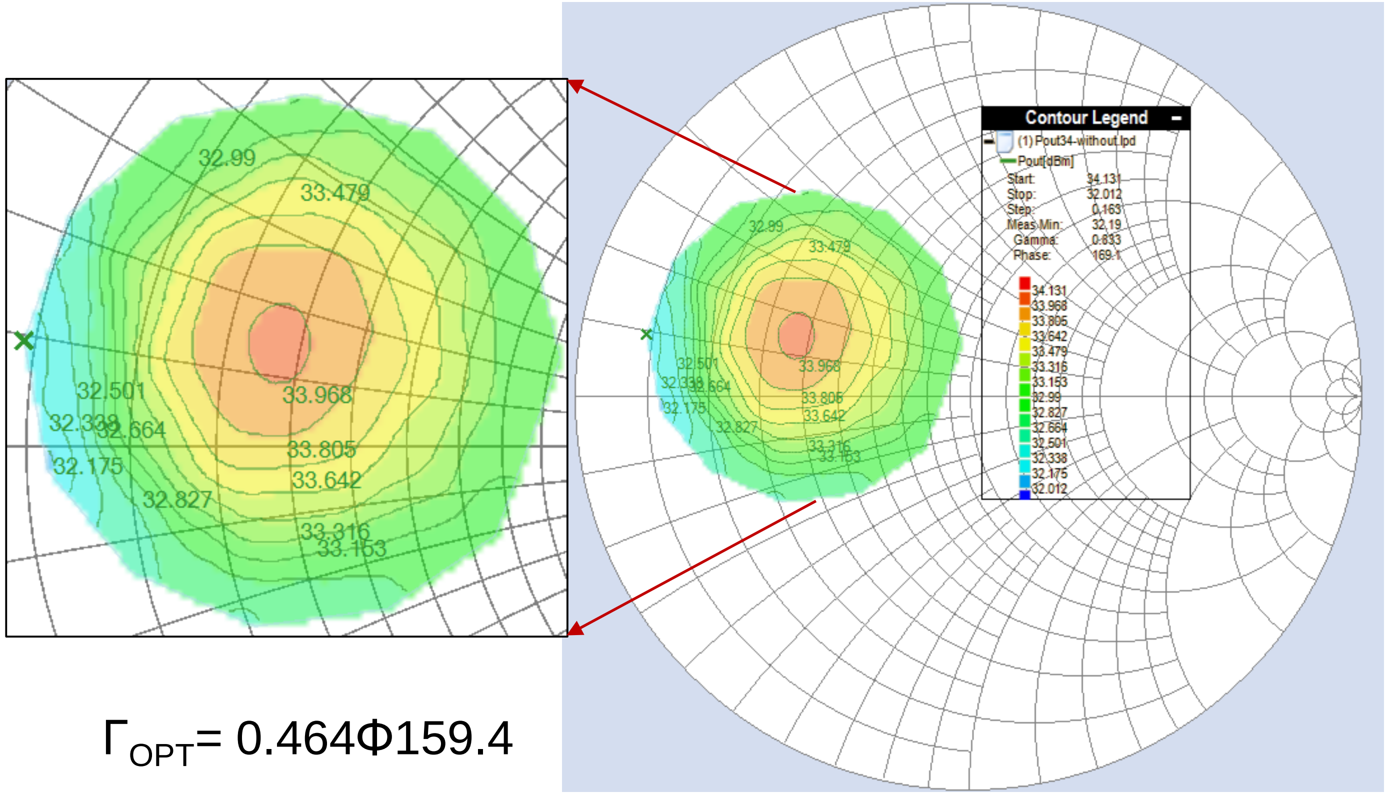
Digital Predistortion & LP Applied Simultaneously

- Both systems utilize PXI chassis-based components.
- All of the RLP and DPD software is controlled using the in-chassis controller.
- Fast PCI based backplane provides the ability to stream and process data to and from both the RLP and DPD systems.
- Real Time Analysis
  - AM-AM
  - AM-PM
  - ACPR



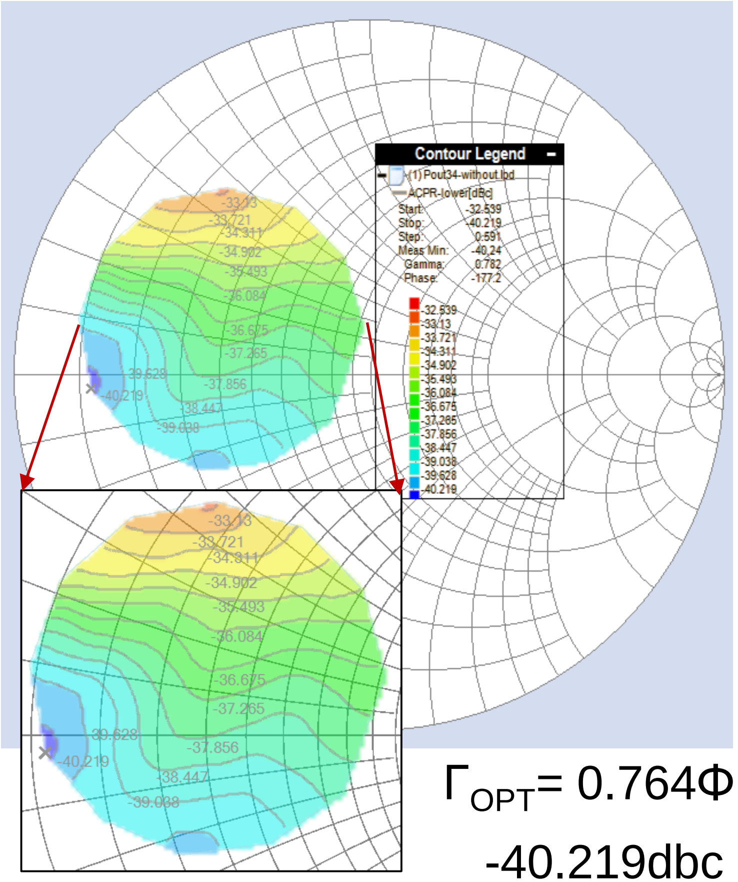
Digital Predistortion

The measurements of a 2W GaN HEMT without DPD



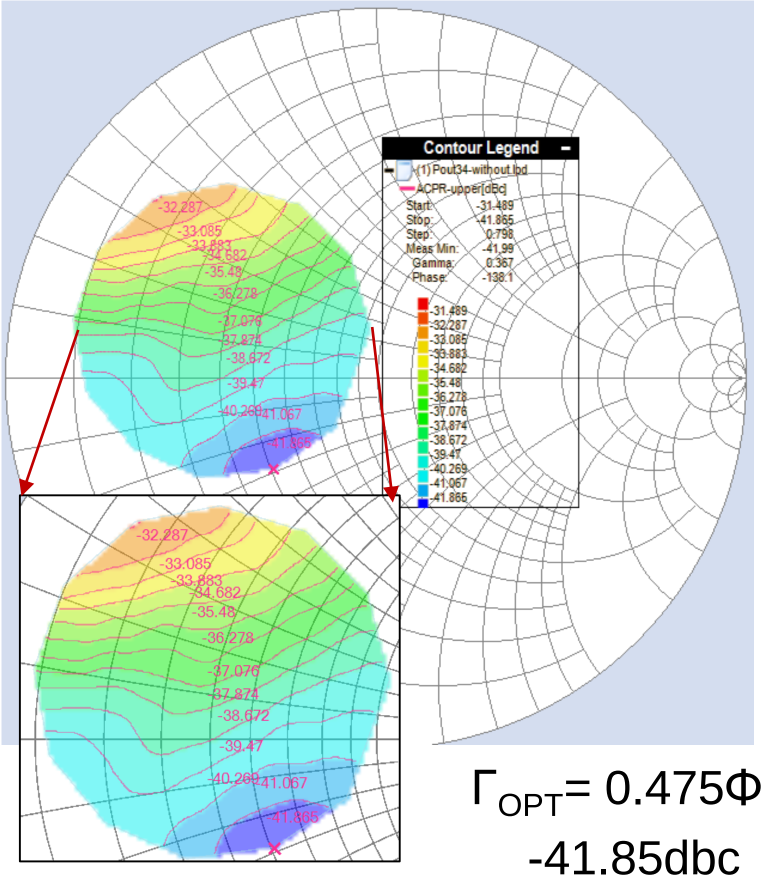
Γ_{OPT}= 0.464Φ159.4

Digital Predistortion



Γ_{OPT}= 0.764Φ179

-40.219dbc



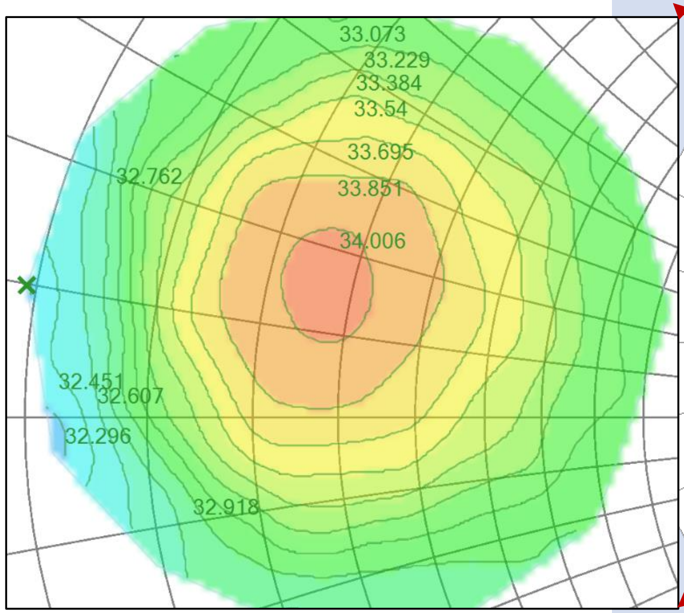
Γ_{OPT}= 0.475Φ157

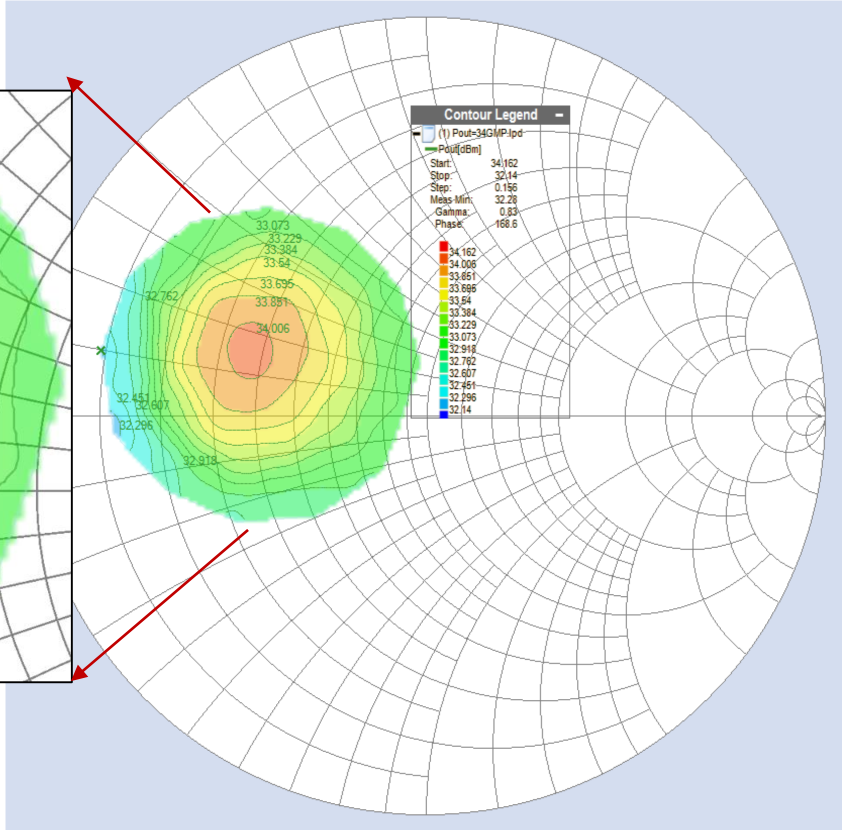
-41.85dbc

Digital Predistortion under Non 50Ω

The measurements of a 2W GaN HEMT with DPD

Pout

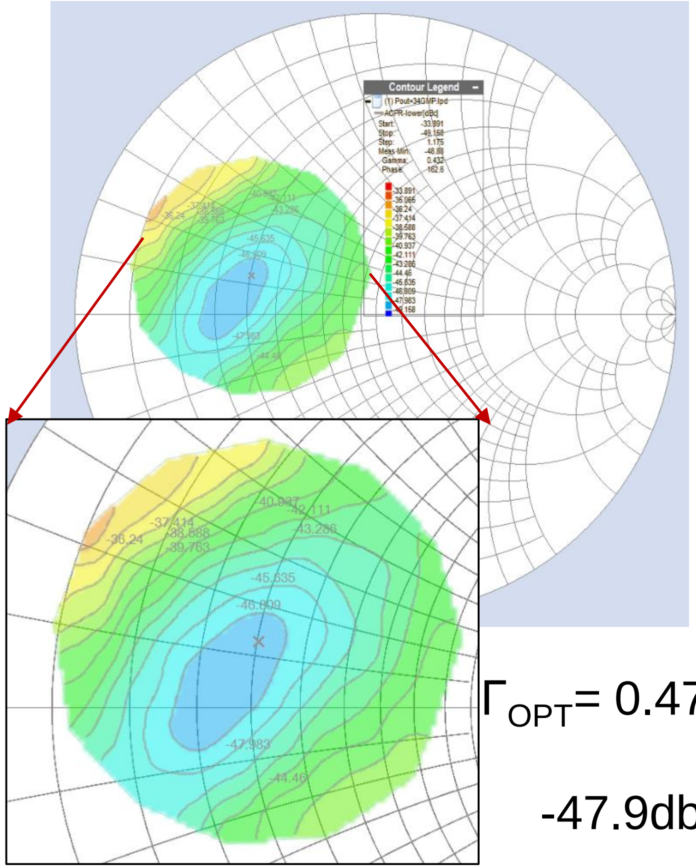




Γ_{OPT}= 0.473Φ153.4

Digital Predistortion under Non 50Ω

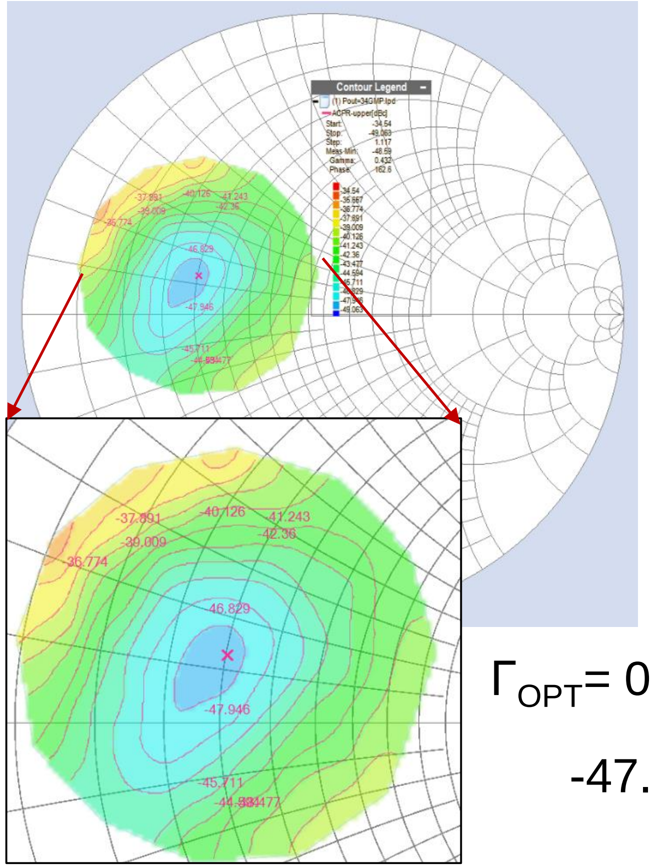
ACPR-Low



Γ_{OPT}= 0.478Φ157

-47.9dbc

ACPR-High



Γ_{OPT}= 0.475Φ157

-47.9dbc

Digital Predistortion under Non 50Ω

- The measurements of a 10W GaN HEMT device have highlighted a large difference in contours with and without DPD.
- Without DPD the Pout and ACPR contours have different optimum impedances.
- With DPD applied both Pout and ACPR contours have aligned hence yielding max Pout and max linearity at same optimum impedance
- The measurements demonstrate that this system combination can be used as a valuable tool in RFPA design to fully characterize the device under realistic modulated and impedance conditions

Conclusion

- The RAPID system is an advanced load-pull tuner that can replace the passive tuner and some measurement equipment in your load-pull bench.
- It has the ability to accurately measure impedance and power, for longer periods of time (tested up to 65 hours).
- Measurement speed with full input and output measurements is orders of magnitude faster than existing load-pull techniques.
- System is also suitable for modulated measurements with 100MHz of instantaneous bandwidth offering the ability to de-skew passive measurements, present wide-band active loads and/or emulate circuits over modulated bandwidth.
- A fully documented API, compatible with most modern programming environments is available for tuner automation.
- Fully automated measurement applying DPD under non 50ohms also presented.

https://focus-microwaves.com/rapid-2/